AD NUMBER
AD398226
CLASSIFICATION CHANGES
TO: **unclassified**
FROM: **restricted**
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to DoD only; Foreign Government Information; NOV 1967. Other requests shall be referred to British Embassy, 3100 Massachusetts Avenue, NW, Washington, DC 20008.**
AUTHORITY
DSTL ltr dtd 15 Feb 2007; DSTL ltr dtd 15 Feb 2007

JOURNAL

OF THE

ROYAL NAVAL SCIENTIFIC SERVICE

Vol. 22 ★ NOVEMBER 1967 ★ No. 6

RESTRICTED

Journal of the ROYAL NAVAL SCIENTIFIC SERVICE

Vol. 22, No. 6 NOVEMBER, 1967

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ARMOUR PLATE UNDER BALLISTIC ATTACK

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Introduction

By definition the purpose of armour is to protect vulnerable structures or equipment from damage by external attack. In armaments alloy steels rolled into plate form, quenched and heat-treated, are the main means of protection, certainly in the field, where the thickness of plate used can range from several inches in the heavy tank to a fraction of an inch in the scout car. Ideally armour should afford complete protection against the more conventional forms of attack, but since in practice there are imposed limitations in the weight and bulk of all armoured vehicles, the aim is to provide armour of optimum resistive properties to such attack, which can range from the solid shot and fragment to the high explosive shell.

The mutual physical reactions that occur during impact between projectile and plate determine the relative efficiency of the plate as a protection and the projectile as the means of defeat. The mechanics of reaction in all real impacts are complex; but simplifying assumptions can be made which allow at least a qualitative understanding of the more important basic features involved. In impacts between steel projectile and steel plate stresses are created of magnitude greater than the elastic limit of one or both of the steels. For moderate impacts an elastic wave of compression is propagated into the materials followed by a plastic wave of lower velocity. Reflections at the free surfaces of both projectile and plate result in rarefaction-type waves or release waves which propagated from a back surface overtake the plastic front and from the front surface collide with it. In both interactions, the plastic wave continues to advance at roughly the same velocity but with reduced stress and appropriate changes in strain and material velocity while an elastic wave is propagated back towards the free surface where, reflected again, the cycle is repeated. For very high impact velocities (and for explosive impacts) the wave propagated is in the form of a shock of pressure far in excess of the yield stress so that flow in regions near to the moving interface between projectile and plate is more in accord with a fluid than a plastic behaviour. However in the intermediate and final stages of such impact, propagation degenerates to plastic and elastic regimes of behaviour. Attenuation by dissipative forces is high, particularly when the plate is subjected to intense shock loading.

In practice because of the finite dimensions of both projectile and plate a large number of reflections and interactions occur in the time of impact and material undergoes a complicated time-dependent or dynamic stress/strain relationship and flows accordingly; but in addition it may undergo rupture or fracture under shear or tension forces. Defeat is in fact due to a combination of failure by flow and by fracture.

This paper is primarily concerned with the broad metallurgical and mechanical aspects of how armour plate responds to loading particularly of a transient nature as in ballistic attack and how response is influenced by the ambient temperature of the plate at the time of loading. These aspects cannot be completely divorced from those involved in plate development, production, testing, proving and quality control, and brief reference is therefore made to them in appropriate parts of the paper.

Forms of Attack

Shot

Not very high impact velocities are needed even between steel and steel to create localised stresses greater than the yield stress of one or both of the steels involved. If the shot is appreciably lower in strength than the plate, a great deal of its incident energy is used up in deforming itself by flow and by fracture, perhaps to violent break-up. If the plate is of appreciably lower strength it yields in flow, material being pushed away to allow the penetrative progress. The associated stress conditions developed at any stage beneath an advancing shot may cause the plate to fail by shear in the form of a plug (Fig. 1) while reflection of stresses from the rear surface may under certain conditions cause failure by tension in the form of a disc. In general, stress interactions are such that plate defeat is due to combinations of penetration by flow, plugging, discing, back petalling and cracking by shear and tension. The relative incidence

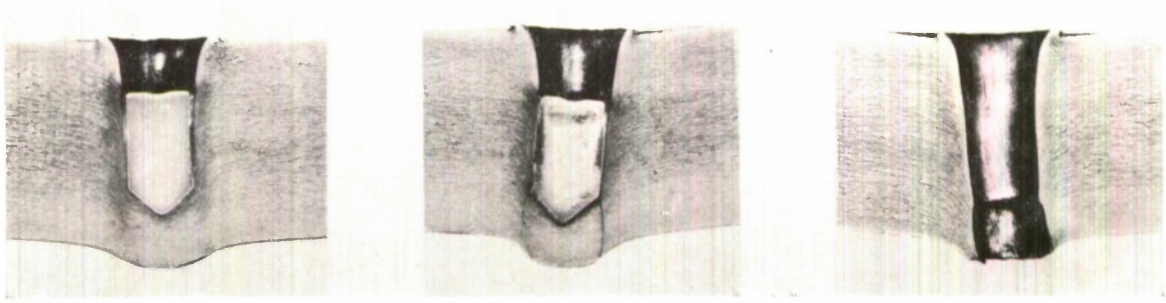

FIG. 1. Successive stages in plate defeat by shot, showing deep penetration by flow with associated radial and rear deformation, and perforation by plugging or dynamic shear failure.

of these main failure processes depends particularly on the ratio of shot diameter to plate thickness, length to diameter ratio of the shot, shape or ogive of the shot and the mechanical properties of both shot and plate. A pointed ogive facilitates lateral flow of plate material, strength with hardness the onset and ease of flow, toughness with dimensional ratios the incidence and characteristics of fracture, whilst angle of impact in including asymmetric conditions can be thought of as influencing and complicating to a more or less extent all the basic processes referred to.

Fragment

The same processes are involved in impact between fragment and plate, but because the fragment in general differs considerably from the shot in shape and dimensions plate defeat is in general more by perforation than penetration in that plugging, discing and spalling are the dominant mechanisms involved (Fig. 2).

H.E. Shell

Since on detonation of the shell on the armour plate the chief agent of attack is essentially a highly compressed gas at very high pressure travelling at very high material velocity, the plate is subjected to an intense shock of duration short compared with that in impact by shot. Whilst such sharp loading is not conducive to large bulk deformation by flow, it is towards fracture, mainly in tension, which occurs when the head of the pulse reflected from the rear free face of the plate exceeds in tension the compression in its oncoming tail (Fig. 3). A disc or scab of the plate separates from the main plate usually with considerable velocity, the process being termed spalling (Fig. 4).

Metal jets from hollow-charge H.E. shells have very high velocities of from 10 to 25,000 ft/sec. At this speed of impact with armour a great deal of the very deep penetration achieved is by flow of a fluid nature and it is only during the last stages of penetration that fracture mechanisms in the form of localised spalling play any part in the process of plate defeat (Fig. 5).

The Resistance of Plate to Attack

If an armour is to have high protection against attack it must be highly resistant not only to penetration but to perforation by plugging and spalling. Now the higher the strength of armour plate the higher is its resistance to flow and hence to penetration, but it is found that though the strength of a steel armour can be increased very considerably by hardening processes, its susceptibility to brittle fracture also tends to increase. Clearly, therefore, the best armour must have properties that are a compromise of high strength with hardness

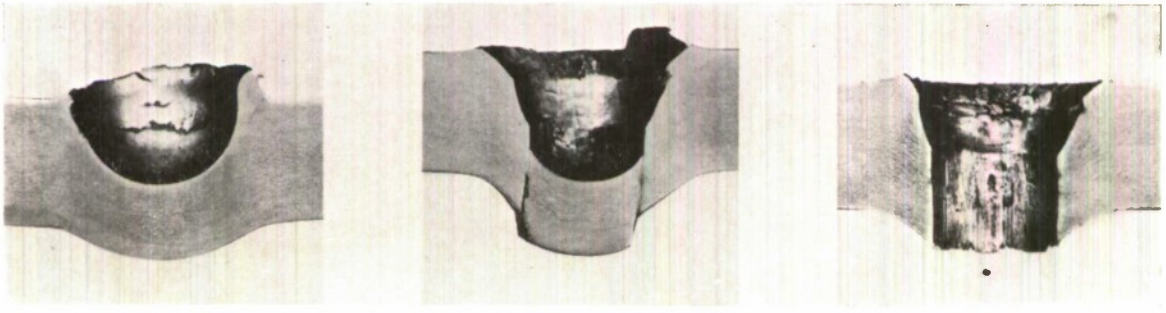

FIG. 2. Successive stages in plate defeat by fragment (sphere) showing penetration by flow with associated radial and rear deformation, and considerable perforation by plugging or dynamic shear failure.

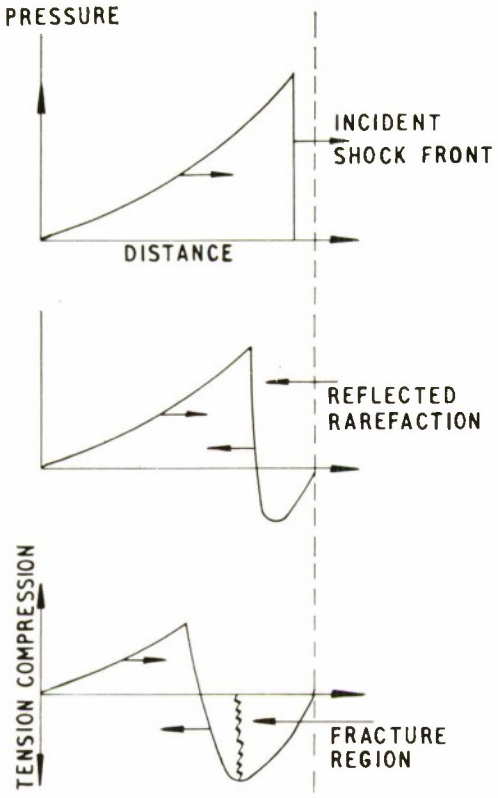

FIG. 3. Successive stages in the propagation of a shock wave at a free surface to produce dynamic fracture and spalling in tension.

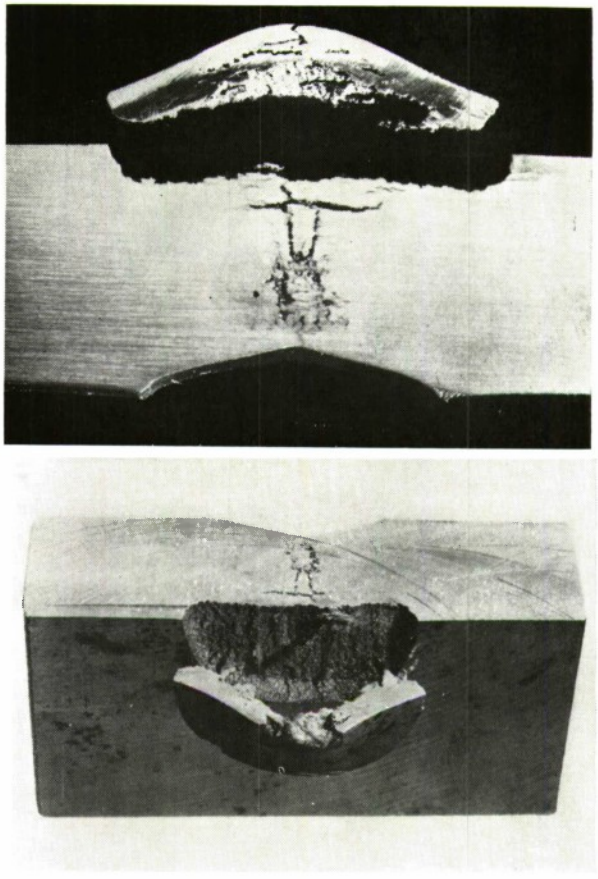

FIG. 4. Plate defeat by detonating shell, showing surface deformation, axial fractures and spalling.

and high fracture toughness when under attack in the field. But such properties are not constant; they change with the conditions of loading and environment, the two most important of which are the rate of loading and the ambient temperature of the steel at the time of loading.

Influence of Magnitude with rate of loading of plate on strength

The strength of a steel (and indeed of all metals) is usually determined from laboratory tests in which a small specimen is subjected to slow tensile, compressive or shear loading at room temperature. But such conditions of loading are far removed from those involved in ballistic attack where the rates of strain may be many orders greater than those involved in static-type tests. There is ample evidence to show that the yield stress displayed by steels increases with the rate of loading. It is observed that for very high rates comparable, for example, with those experienced under detonation forces in ballistic attack (strain rates of about 10^6 sec^{-1}), the stress at which a steel yields is a few times greater than that under slowly applied loading or so called " static loading ". The time-dependent yield response of steel to external loading must therefore be borne in mind whenever the values quoted are strictly those derived from static-type testing.

On Fracture Toughness

Steels that are of high strength and toughness under static loading exhibit increased susceptibility to fracture when subjected to dynamic loading of equivalent energy. In the laboratory there are many tests designed towards revealing the fracture toughness of metals. One that is considered of particular importance for steels is the Charpy test in which a notch is cut in the middle of one face of a small rectangular specimen, which supported at both ends is subjected on the face opposite the notch to a blow of known energy. The stress transmitted initiates a crack at the base of the notch which may propagate across the specimen to produce complete fracture. For a given steel specimen the energy absorbed to produce complete fracture

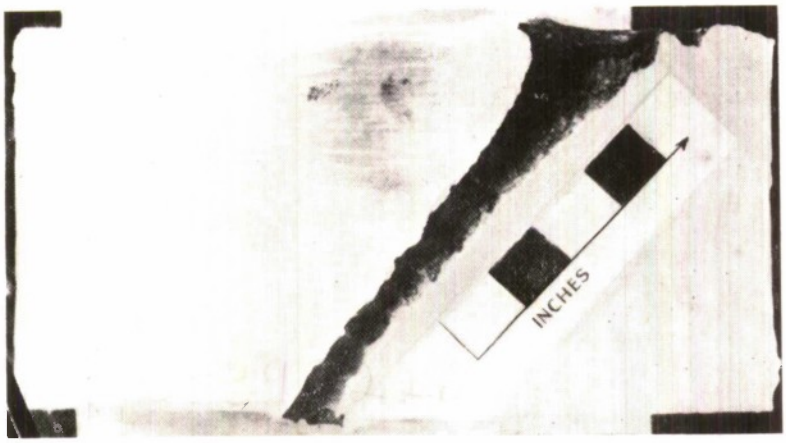

FIG. 5. Plate defeat by jet from hollow charge shell, showing very deep penetration by flow mechanisms and localised rear surface spalling.

is dependent on the geometry of the notch; but for constant notch characteristics and within limits, the harder the steel the less is the energy needed to cause fracture.

Experiments reveal that the stress at which fracture occurs is dependent on the rate of loading. For example, at rates associated with explosive loading, the fracture stress in tension for various metals including steel is deduced as at least an order greater than that under static loading. Whilst loading in the Charpy test is certainly not of a static nature, its rate (strain rate in the vicinity of the root of the notch about 10^3 to 10^4 sec^{-1}) in general is a few orders less than that imposed in the severest ballistic type attack. As for yield strength so is the fracture strength dependent on rate of loading. This time-dependent response of plate in terms of flow and fracture must therefore be appreciated and must be borne in mind whenever the values referred to are those derived under static conditions of loading. Shock loading is of a nature particularly conducive to tensile fracture or spalling. Even if the pulse is not intense enough to cause fracture after one reflection from the rear surface of the plate, interaction of reflections may result in a build up of intensity sufficient to cause fracture.

The Influence of Temperature of Plate

Under operational conditions in the field, armour may be at temperatures ranging from −60°F. to 100°F. and it is therefore of great importance to know to what extent its resistive behaviour under attack is influenced by temperature.

On Strength

Within limits a steel specimen under static conditions of loading increases in yield stress with decrease in temperature, but the work needed to cause ultimate failure tends to diminish. Corresponding behaviour is observed at higher rates of loading.

On Fracture Toughness

The Charpy test shows that as the temperature of a steel is decreased the energy required to fracture it decreases (Fig. 6). At the higher temperature it possesses ductile properties in that incident energy is largely used up in flow; but as the temperature is decreased it becomes less ductile until it tends to exhibit brittle properties, in that it fractures for very small amounts of incident energy. Many armour steels exhibit fairly rapid transitions from ductile to brittle characteristics within fairly narrow ranges of temperature.

Ballistic Resistance

To carry out extensive observations on the way temperature influences the resistance of plate to various forms of ballistic attack in the field is obviously a difficult and costly procedure. It is important to know, therefore, how far and to what degree of reliance information gained from laboratory tests can be used in the development of plate of high ballistic resistance.

From what has been said the more intense and transient the nature of the loading, the more susceptible is the plate to failure by fracture. It would be expected, therefore, that under ballistic attack, the resistance of plate to fracture would certainly be no less sensitive to temperature, particularly in

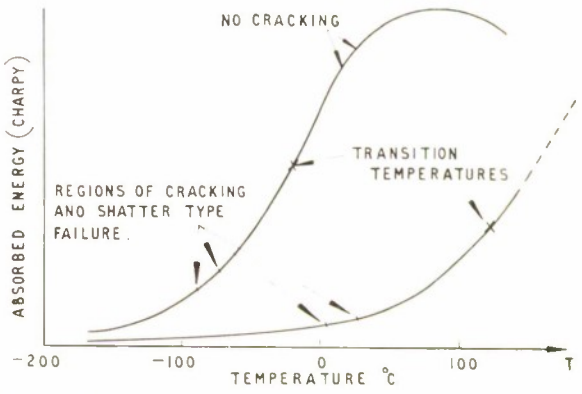

FIG. 6. Illustrative correlation of ballistic resistance of armour plate with Charpy properties within a range of operational temperatures.

the lower ranges, when brittle-type failure should occur. Certain firings of shot and shell against homogenous type armour at various temperatures have shown specific aspects of correlation with Charpy/temperature characteristics (Fig. 6). At temperatures some 25°C. above the Charpy transition temperature, the plate exhibits much more resistance to defeat than at the same temperature below this, when the incidence of brittle-type failure may be high. Within this temperature range of about ±25°C. behaviour is erratic, as would be expected from the relatively rapid transition from ductile to brittle properties.

Tests of Plate Quality

The mechanical tests of strength and toughness referred to are of course supplemented by others, well-known and of the same general features: they need not be referred to here. Strictly all such tests are on small samples, the measured values of which are attributed to the whole of the parent plate and possibly to a batch of plates from the same cast. No plate can be perfectly homogenous and isotropic. Some may contain more or less gross defects that might seriously impair the overall resistive quality expected of the plates and which could not possibly have been detected by the tests referred to. It is obviously important that all plates accepted for use particularly in vehicle construction and projectile development are of high quality and consistency in performance. To ensure that they do not contain undetected defects of a serious nature non-destructive tests are used embracing X-ray and ultrasonic techniques. For a number of reasons the former test is used only in special circumstances: the latter method is increasingly used and may be worthy of brief description.

Ultrasonic Inspection

Steel armour plate can easily be inspected with ultrasonic techniques to detect internal defects such as inclusions, cavities, laminations, *etc.* It is also possible to use ultrasonic attenuation measurements to study the metallurgical structure, but attenuation measurements for this application are not yet in general use. Flaw-detection techniques are well established.

For flaw detection, an ultrasonic probe consisting of a disc of piezo-electrical material (with a voltage applied) is pressed against the surface of the armour plate, using a coupling liquid to ensure good acoustic contact; this coupling liquid is usually oil or water. A suitable ultrasonic probe frequency for this work is between 2 Mc/s and 6 Mc/s.

Pulses of ultrasound emitted by the probe pass through the coupling liquid into the steel and are reflected by any internal discontinuity, and by the surfaces of the steel plate. These pulses of ultrasound can be longitudinal or transverse vibration waves, but for armour plate inspection longitudinal waves are usually employed. The reflected signals are displayed on a cathode ray tube on which the time base is suitably expanded so that the reflected pulses from the front and back surfaces of the plate are separated by the full width of the display screen (Fig. 7). Internal flaws create reflected pulses that give signals on the screen in between the front and back surface signals. The height of the signal obtained from an internal defect depends on the size of the defect and on its acoustic reflecting power, but for the flaws usually found in rolled armour plate it is possible to estimate both the size and position of the flaw reasonably accurately.

There is no difficulty in inspecting armour plate of any thickness between $\frac{1}{4}$ in. and 30 in. and flaws of area larger than $\frac{1}{8}$ in. x $\frac{1}{8}$ in. should be easily detected. For inspecting large areas of plate the probe is built into a sliding or rolling head with continuous irrigation of the coupling surface with oil or water from a reservoir. The probe head is slid over the plate surface in a grid pattern while an inspector watches the cathode ray screen. Automatic systems which operate an alarm when any defect signal larger than a pre-determined size is shown, can also be used.

This method of testing plate for internal defects is cheap and easy to perform. It gives accurate information about the position and size of defects and usually the nature of the defect can also be deduced. It does not directly give information on the significance of defects.

General Comments

In the present state of knowledge it is believed that the sequence of events leading to tensile fracture at slow or moderate rates of strain can be explained on the mechanical basis of the high shear stresses generated during loading and the consequent cracking of brittle micro-constituents such as cementite (Fe_3C) at an early stage of deformation, or in more ductile materials, the initiation of micro-cracks at a later stage as a consequence of dislocation (a lattice imperfection) interaction. A dislocation pile-up at an obstacle such as a precipitate or grain boundary can generate high tensile stresses. The micro-cracks created by one or other of these mechanisms extend under tensile stress, and in brittle materials the stress concentration at the crack tip will be sufficient to propagate cleavage or intergranular cracking with very little plastic flow. In ductile metals extensive plastic flow near the crack tip is required for further propagation. At some stage in the crack growth the Griffith-Orowan criterion (crack criticality) will be satisfied and the fracture will suddenly propagate to completion.

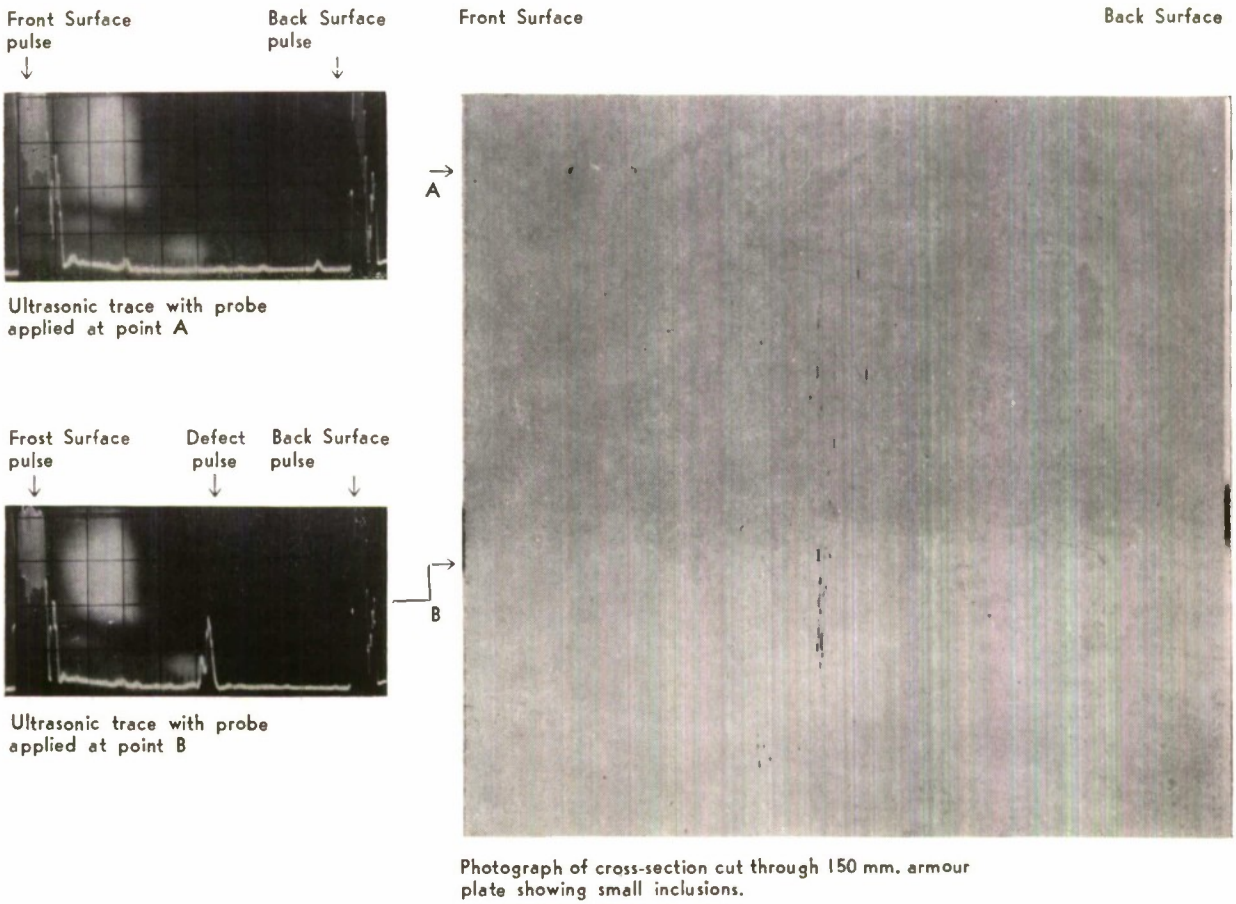

FIG. 7. Non-destructive testing of armour by ultrasonic technique.

Since the velocity of dislocation movement and crack propagation cannot exceed the velocity of elastic waves (or sound) in the material, it is possible that in regimes of impact where intense shocks are propagated with velocities even exceeding the normal velocity of elastic waves the influence of dislocations is of secondary importance in that though they might be generated they would tend to lag behind the shock front. The stresses generated exceed the static shear stresses by a few orders of magnitude and flow assumes a hydrodynamic nature in which compressibility and viscosity are controlling factors. At later stages in the propagation stress is reduced and failure by fracture assumes a dominating rôle, because of the influence of attenuation and rarefaction.

Fracture in metals can be produced by a wide variety of conditions such as creep, fatigue, stress-corrosion, and hydrogen embrittlement. In the present context of those that are produced by ballistic attack there are three categories of fracture: shear, cleavage and intergranular.

The so-called ductile or tough fracture is produced by the interactions of large shear strains in adjoining crystals, but the "plugging" phenomenon referred to in armour is a more obvious example of shear failure where there is evidence of localisation of shear in narrow bands by the heat generated during deformation, so that at such high rates of fracture the process of shear is adiabatic. Brittle fracture along the crystallographic cleavage planes occurs at stresses that are several orders of magnitude smaller than those predicted from interatomic action, and therefore various models have been proposed that could lead to the stress concentration needed to initiate fracture. These models involve interaction between deformation twins, or more generally between dislocations (an edge dislocation or large Burger's vector necessarily produces a crack nucleus). Such stress concentrations lead to fracture only if they are not absorbed or relaxed in plastic flow while they are building up, and in this respect low temperautres and high rates of strain must assist

crack nucleation. This is the fundamental explanation for the well-known fracture transition that takes place in body-centred-cubic metals with decreasing temperature. Since dislocation movement is needed to generate the stress concentration which initiates fracture, it can be appreciated why in several investigations the cleavage stress has been found equal to the yield stress, or that cleavage and yield stress both vary with grain size in accordance with the Petch relation. Intergranular fracture can be induced by thin films of brittle substances, such as iron sulphide, at the grain boundaries, but the well-known phenomenon of temper brittleness is still not adequately explained. Quite severe temper brittleness has occasionally been found in thick armour of alloy steel, and there is no doubt that the intergranular fracture which is characteristic of this phenomenon is produced by grain boundary segregation; but direct evidence for this segregation has yet to be found. The main driving force for this segregation is the energy reduction that occurs when a solute atom which is larger or smaller than the solvent lattice, finds an enlarged or compressed vacant site in the disturbed transition zone between one crystal and the next. The elements phosphorus, antimony, tin and arsenic have been shown to be largely responsible for temper brittleness (with phosphorus still the chief cause, at least in the experience of R.A.R.D.E.). The elements molybdenum and tungsten ameliorate the effects of these elements, perhaps by competing for the same boundary sites and providing stronger intercrystalline bonding.

The problem of failure of armour steels by fracture is clearly of paramount concern because as has been discussed, the general nature of ballistic attack is conducive to such failure, as are prevailing low field temperatures during attack. The degree of cleanness of plate and the amounts of residual elements like phosphorus, sulphur, arsenic, antimony, tin, oxides and nitrades are of considerable importance in the mechanical properties of the plate and hence in the way it responds to attack. Rolled plate tends to incorporate discontinuous layers of various inclusions and alloy segregations. Such layers are planes of weakness under stress and are conducive to discing and spalling. Whether they exhibit fracture under dynamic tensile action depends on the position of the plane relative to the rear face of the plate and on the form of the attack. The type and amount of interstitial elements also play a part particularly in the way fractures are initiated under various forms of loading.

A wide variety of alloy steels could be used to make good quality armour, but it is important that the content and balance of alloying elements should be sufficient to provide a fully martensitic structure on quenching. Full hardening becomes more difficult with thickness of plate, and where the steel is not fully hardened before tempering, the toughness is measured by Charpy tests is generally inferior. Subject to effort and cost, it is undoubtedly right to attempt to make steel of high purity. Recent trends in steel making are towards wider use of pure charges, improved refining and degassing and growing application of vacuum melting techniques. High consistency in performance under nominally identical conditions of attack is, of course, an important aspect in any worth-while improvement. Overall improvement in ballistic performance implies appropriate enhancement in strength and toughness characteristics, and a most important physical aspect to be appreciated in any development directed towards such improvement is the influence of rate of strain with therefore the need to establish correlations between response factors derived from laboratory tests and ballistic trials.

Conclusion

The resistance of armour steels to ballistic attack depends on their qualities of strength and toughness, which are complementary only within a range of hardness, so that optimum plate performance are compromises in strength and toughness characteristics. Toughness in particular is also related to temperature, which under operational conditions ranges from about $+40°C.$ to $-60°C.$, and since transitions in behaviour from ductile to brittle can occur within a range of about $\pm 10°C.$, a high performance armour should exhibit high toughness (or low susceptibility to fracture) at the lowest temperatures. As for all materials, the response or performance of armour depends on the rate at which it is loaded. Adequate correlations between aspects in performance at low rates as usually determined in the laboratory with those at ballistic rates are therefore sought in the course of armour development.

Acknowledgements

Thanks are due to Messrs. H. G. Baron, R. Halmshaw, T. Williams and L. Permutter of R.A.R.D.E. and Dr. J. F. Alder of F.V.R.D.E. for discussions and contributions.

NON-DESTRUCTIVE TESTING AT BRAGG LABORATORY

S. Bagley, A.N.D.T.S., A.M.I.E., R.N.S.S., and A. Muscott, B.Sc.(Tech.), A.M.C.T., R.N.S.S.

Introduction

Non-destructive tests by definition are those tests which do not damage or impair the serviceability of the items tested and hence Non-Destructive Tests can, if necessary, be applied to all critical components and assemblies. By contrast destructive tests can only be made on prototypes or a small per cent of production parts. Destructive tests cannot provide a guarantee that the items which are passed into service do not contain a significant defect nor that the items retained in service have not developed significant defects.

Non-Destructive Testing can be applied along a production line with feedback of information concerning critical variables, so that the process may be controlled to maintain the variables within acceptable limits. This is easy with variables such as dimensions, concentration of fluid, pH, *etc.* However, many defects such as of metallurgical quality, *etc.* are of a discontinuous nature and are less readily condensed into a simple variable which can be regulated in a production line.

In the field of weapon manufacture, a component, or even a raw material may pass through many very different stages of manufacture. Often the most appropriate stage of inspection occurs with the change of Contractor. Any visitor to an explosives proof yard cannot fail to be impressed by the tremendous power of quite tiny quantities of explosives, detonators, *etc.* Modern Naval Weapons are often extremely complex (and expensive) and it should be readily appreciated that within the Naval Ordnance Inspectorate, the prime concern is safety, *i.e.* the certainty that every component or weapon will function correctly. In principle, other factors such as avoidance of scrap and re-work are of secondary consideration, but the Inspection Authority may be under extreme pressure to make rapid assessment of serviceability and non-destructive testing may be the quickest as well as the best means of inspection.

The prime function of the Non-Destructive Testing Section of the Bragg Laboratory is the selection and special development of the basic techniques, summarized in Table 1, to detect irregularities and failures of Naval Armament Stores, in manufacture, proof and service, often as a direct corollary of metallurgical investigations. (A notable exception is radiography. This could not be properly housed at N.O.I.E., Sheffield, because of the radiation hazard and is centred at Woolwich). Not surprisingly, several of the examples which are described in detail are in the field of ultrasonics where advantage has been taken of the very great improvements in equipment, probes, techniques, *etc.*

Ultrasonic Applications

Table 2 lists some of the current applications. Where possible, in the detection of defects or discontinuities, reflection methods are preferred to transmission loss methods and for high sensitivity, the frequency is kept as high as possible, consistent with the scattering and attenuation characteristics of the particular medium. Generally, fine grained metals are good transmitters, whilst coarse microstructures, plastics, and composites generally exhibit high damping.

Non-Destructive Testing of Steel Cartridge Cases[1]

Rapid firing guns use fixed rounds of ammunition and high speed, powered ramming of the round into the breech of the gun. In order to retain the projectile correctly throughout handling and ramming, the cartridge cases are required to have strong mouths. For example, the 'bullet pull' of a modern round may be 10 tonf. or more. Such values can only be obtained in brass, the traditional material, when this has been considerably work hardened to raise the

TABLE I.

Basic Principle	*Variation of Main Principle*	*Applications*
Penetrating radiations	Radiography	Internal defect detection
	Colour radiography	Discrimination of complex internal detail
	Fluoroscopy and Xero-radiography	Internal defect detection
	Radio-isotopes	Flaws in heavy sections
	Auto-radiography	Defects in reactor fuel cans
	Pulsed X-rays	Moving subjects, e.g. machinery, and defects in hot billets
	Neutron radiography	Internal defects in thick sections of heavy metals, non-metallics, rubber, plastics and wood. Detection of inclusions containing hydrogen
	Beta ray back scatter	Thickness measurements on electro-plates
Ultrasonics (approximate frequency range 20 Kc/s — 200 Mc/s)	Transmission contact or immersion	Internal defects in metals, plastics and rubber Continuity of bond in multi-layers
	Pulse echo using:—	
	(i) compression waves	Internal defects
	(ii) shear waves	Internal defects, surface cracks
	(iii) surface waves	Surface defects, e.g. cracks and laps
	(iv) Lamb waves	Defects in thin plates
	Resonance	Thickness measurement and lamination detection
	Pulse interference	Thickness measurement—thin walled tubing or thin foil
	Frequency analysis (ultrasonic spectroscopy)	Defect type identification
	Ultrasonic imaging	Internal defect detection in small sections
	Phase detection	Detection of unbond in multi-layers
	Attenuation measurement and comparison	Material structure comparisons. Grain size comparison
	Polarization of shear waves	Internal stress determination
Sonics (approximate frequency range 20 Kc/s	Resonance	Measurement of physical constants
	Frequency analysis	Defect detection
	Phase difference measurement	Bond testing multi-layer bonds
	Acoustic Emission	Detection of crack initiation and propagation
Electro-magnetic Eddy current	Impedance variation	Sorting components or materials in terms of composition, metallurgical condition or dimensions. Surface crack detection
	Reactance variation	Coating thickness measurement
	Loss sensitive	Measurement of case depth and depth of decarburisation
	Phase sensitive	Thickness measurement and defect detection
	Frequency sensitive	
	Field penetration—shielding effect (Transmission technique)	
Static Magnetic Field Tests	Retentivity	Determination of mechanical and metallurgical condition, case depth, and alloy content
	Coercive force	Non-magnetic wall thickness measurement
	Permeability	Coating thickness measurement on ferro-magnetic bases
	Magnetic Traction Pull-off and balance methods	
	Magnetic leakage field pick up	Surface defects in ferro-magnetic materials
Magnetic Particle	Indication by:— (i) Dry powders (ii) Inks (iii) Fluorescent inks Magnetisation by: (i) A.C. (ii) half wave rectified A.C. (iii) full wave rectified A.C. (iv) pure D.C. (v) permanent magnet	Surface flaw detection in ferro-magnetic materials

TABLE I (Contd.)

Electrified Particles e.g. Statiflux		Surface defect detection in insulating materials, e.g. glass, plastics, alumina.
Thermal	Thermo-electric Thermal conductivity	Sorting on composition and metallurgical variations. Plating thickness measurement
	Infra-red transmission	Detection of discontinuities that cause heat transfer changes
	Infra-red camera Cholesteric Liquid Crystals	Bond testing and detection of defects which affect flow of thermal energy.
Penetrant	Dye Fluorescent	Surface defect detection in metals and plastics
Micro-waves	Transmission	Flaw detection in non-metallics, e.g. plastics, rubber and ceramics
	Reflection Attenuation	Dimensional measurement Bonding defects, resin/glass ratio, detection of porosity and delaminations. Moisture content and state of cure
Electrical	Conductivity A.C. or D.C. resistance or volt drop measurement	Surface crack depth determination. Spot weld soundness. Pin-hole detection in paints, lacquers and other non-conducting coatings on metals
	Permittivity or loss tangent variation	Material uniformity and thickness variations in dielectrics
	Tribo-electric method	Identification of materials using The Tribo-Electric Series
	Ionisation testing	Tests on insulating materials. Maximum safe working voltage determination
Miscellaneous and fringe methods Visual	Boroscopes and microborescopes	Inspection of internal surfaces such as bores and recesses
	U.V. endoscope	Viewing fluorescent dye indications (either penetrant or magnetic ink) in cavities, pipes, etc.
Strain gauging	Photo-elastic coating (e.g. Stresscoat)	Surface strains and residual stress Detection and analysis
Spark Testing		Sorting by composition (e.g. carbon in steel)
Leak Testing	Ultrasonic Hydrostatic Helium leak detectors	Detection of leaks in vacuum vessels, boilers, etc. Leak detection in pressure vessels Testing of electronic device seals e.g. solid-state device encapsulations
Micro-hardness Ultrasonic Hardness Measurement		Measurement of hardness by small indentation Direct reading of hardness producing only a minute indentation
Electro-chemical Weisz 'ring oven' and electrographic sampler		Sorting of carbon and low alloy steels
Chemical spot tests		Qualitative indication of presence or absence of an element
Local penetration of coatings	Drewitt Thickness Gauge	Coating thickness measurements by detecting change in resistance to penetration occurring at the coating/base metal interface

TABLE 2. Ultrasonic Applications.

Broad field of inspection	*Naval Ordnance Application*	*Technique*
Examination for defects e.g. piping, thermal cracks, hair line cracks, fatigue cracks, inclusions, porosity and other discontinuities	Inspection of welds in pressure vessels and in test coupons. Gun forgings (Barrels and breech rings) Cartridge cases Material in plate, bar, and tube form. Rubber transducer windows and couplings	Shear wave double probe system Shear wave single probe system Compressional wave single Single shear, and combined compressional wave double crystal probe Miniature shear wave Method depends upon size and geometry Double probe transmission
Bond quality	Epoxy resin metal/metal bonds Hard facing bonds Spot welds	{ Miniature combined focused double crystal compressional wave probe Miniature single crystal or double crystal combined compressional wave
Grain size comparison and material structure variations. Material properties attenuation and ultra-sound velocity	Steel and brass Rubber	Attentuation comparison using multiple echo rate of decay, with a calibrated attenuator Calibrated attenuator Pulse interference
Dimensional Measurement	Residual thickness of mortar barrels Sheet thickness	Pulse echo using a fast time-base and double crystal compressional wave probe with delay. Resonance

elastic limit. Since no thermal stress relief can be applied to the mouth of a filled case after assembly and indenting of the mouth around the projectile, there is a very serious risk that residual stresses remaining from these operations will cause season cracking in prolonged storage, particularly since traces of nitrous gases may be formed inside the filled case.

This difficulty was readily overcome by changing the material to steel, which is not liable to stress corrosion cracking in this manner. However, for very easy extraction of the spent case, it is essential that the base end of the cartridge case has a high elastic recovery and in steel which has a high modulus of elasticity, this cannot be achieved without a very high elastic limit.

Hence, it was necessary to select a steel which, whilst capable of severe deep drawing, could be locally hardened and tempered to around 95 tonf./in.^{2} U.T.S. At this strength level the fracture toughness of the steel is low and quite small defects, *e.g.* fine cracks or inclusion stringers can initiate failure. Firing imposes an impulsive hoop stress which is transverse to the drawn structure and at some places transverse to the macro-structure of the steel, persisting from the hot-rolling stages of the manufacture. For years, a very small percentage of cases split on firing (see Fig. 1(a)) and although the results were not catastrophic, sometimes the gun was stopped and occasionally secondary damage occurred. An unfortunate feature of all cartridge failures is the partial fusion of the fracture surfaces by the escaping hot propellant gas. Although the resultant metallurgical investigations of the failures were thus made difficult, it was suspected that the fractures had been initiated by a very small crack in the inside wall, close to the base, where visual and magnetic particle detection were extremely difficult to interpret. After ultra-

sonic examination of a large number of cases, it was confirmed that a very small proportion contained a single, short, fine hardening crack, $\sim \frac{3}{8}$ in. long $\times \frac{1}{32}$ in. deep. Test firings carried out on cases selected after classification of suspected defects, *e.g.* short cracks, inclusion stringers, surface folds, *etc.* confirmed that the splits were due to very fine cracks (see Fig. 1(b)) and that other defects were relatively innocuous.

As a result, 100% ultrasonic crack detection was instituted. The present method (see Fig. 2) uses a standard flaw detector unit with miniature shear wave probes (45° and 70° angle) which are scanned longitudinally over the lower wall whilst the case is rotated automatically. The sensitivity of the instrument is standardised on an artificial defect and any case which gives a response comparable with this standard is segregated for detailed evaluation.

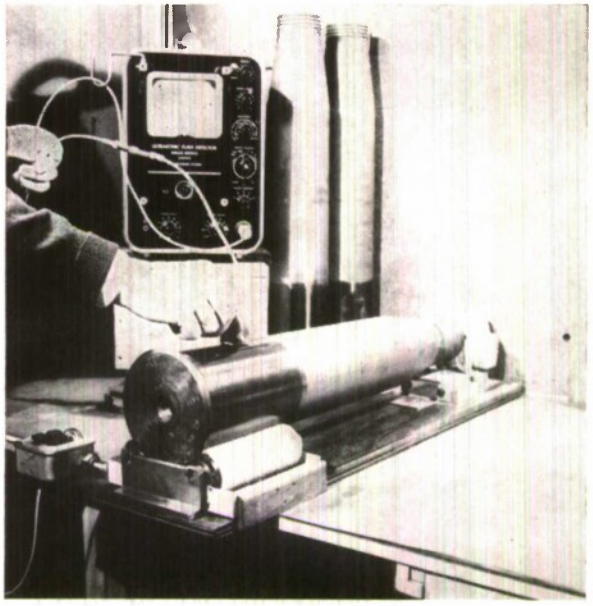

FIG. 2. Ultrasonic flaw detection of cartridge case.

Difficulties due to 'dead zone' and 'near zone' effects are minimised by detecting the defects after a series of multiple reflections within the wall of the case (see Fig. 3). This technique also gives ample warning of the approach of a flaw to the probe by using a

FIG. 1(a). Cartridge case split on firing.

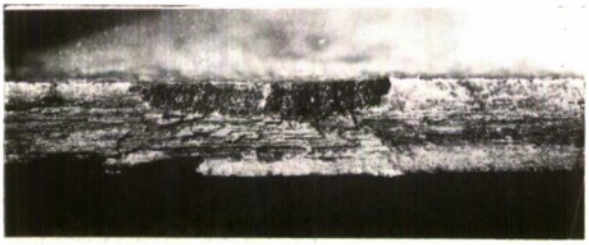

FIG. 1(b). Fracture surface showing cracked area.

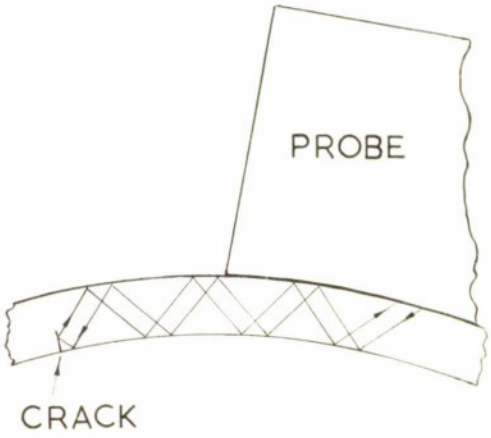

FIG. 3.

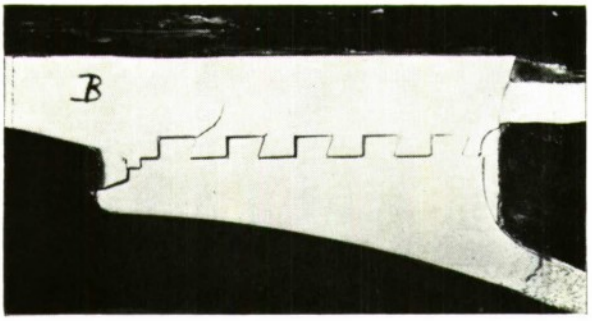

FIG. 4.

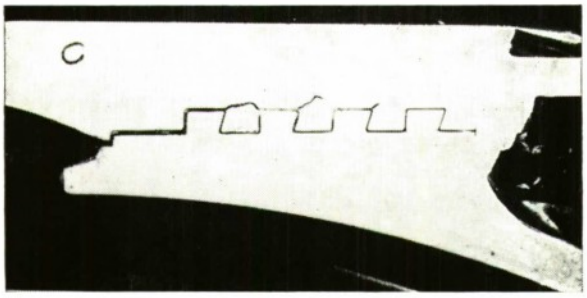

FIG. 5.

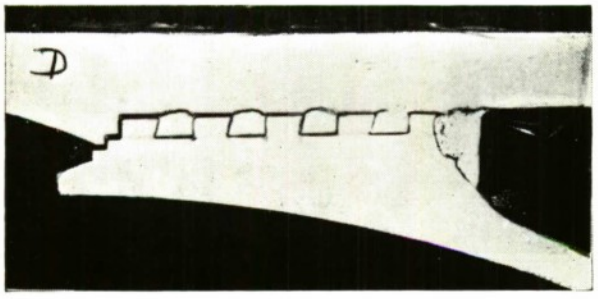

FIG. 6.

time base range which is large compared with the transit time for a pulse to complete one ' skip ' distance. Discrimination between inclusion stringers and cracks is aided by using the flatter beam (70°) after the initial rapid 45° sorting scan.

To date, none of the many thousands of cases passed by the present method has split on firing. However, work is proceeding to develop a more automatic contactless immersion method using focused compressional wave probes and incorporating a flaw alarm system. This will have the advantages of eliminating operator fatigue and probe wear and still accommodate a range of similarly sized cases or other thin walled tubular components.

Ultrasonic Detection of Fatigue Cracking in 21 in. Air Vessel[2]

Accelerated life tests on high pressure air vessels have shown that fatigue cracks can develop in the roots of the special buttress threads which retain the dome ends of the vessel. A non-destructive test method has been prepared to certify freedom from such cracks, especially in view of possible extension of the service life of the vessels. Samples of thread roots which contained gross cracks, from air vessels which had been tested to destruction, were obtained for initial development of the technique. This was then refined using smaller artificial cracks 0·03 - 0·06 in. deep which were cut into sound samples in the laboratory. Figs. 4 - 6 show grossly cracked samples in which the edges of the cracks have been delineated by magnetic particles. For easy reference, the samples were classified as follows:—

TABLE 3.

Sample	*Crack Type*
B	Type 1—penetrating body wall
C	Table 2—bridging the threaded sections
D	Table 2—bridging the threaded sections

A number of possible ultrasonic techniques was investigated[2], and a shear wave method using a miniature 45° angle shear wave probe was selected as the most suitable for routine examination of a large number of vessels.

In the preliminary tests, a Krautkramer USIP10W general purpose flaw detector was used, but the detailed test instruction was subsequently modified to suit the Ultrasonoscope Mk. 5 portable flaw detector, of which a greater number are available throughout M.O.D.(N). Either instrument is suitable, the main requirements being high frequency range, short dead zone and fast time base.

Standardization and Testing

The leading edge of the transmission pulse is initially set to zero and the crack-free standard is employed to obtain marked echo positions from the thread corners indicated in Fig. 7. A succession of strong corner echoes is obtained when the probe is scanned longitudinally towards the free end of the

standard. The echo response from corner 'a_2' is optimised by adjustment of the probe position and the peak height set to a datum on the vertical (amplitude) scale. On transferring to the vessel the probe is initially located by a thread position indicator and scanned as for the standard. Any large crack of Type-1 is clearly indicated by complete cut-off of the 'a' corner echo and the appearance of a new echo which moves to a shorter time base position as the probe is moved longitudinally (see Fig. 7). This is the most important feature of the method and quite clearly indicates this type of crack. Gross Type-2 bridging cracks are detected by the absence of 'a' corner echoes. Small cracks which have not clearly developed into Type-1 or Type-2 cracks are detected by a new echo from the crack and partial loss of the 'a' corner echo (see Fig. 8).

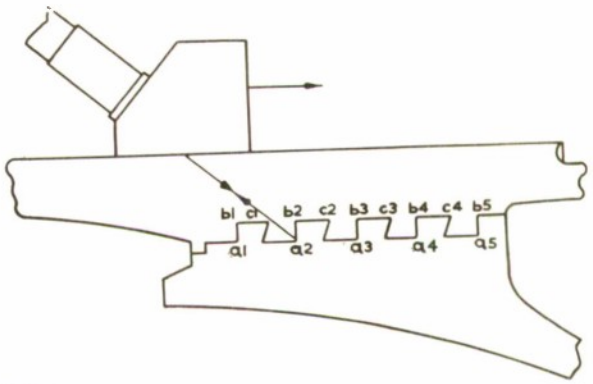

FIG. 7.

Similar longitudinal scans are then carried out at intervals along the circumference at each end of the vessel. Since the ratio of circumferential length to radial depth of the cracks is high, it is unnecessary for scans to overlap and with further experience it may be possible to increase the spacing of successive scans.

At present it is considered that cracks down to 0·030 in. depth should be detected.

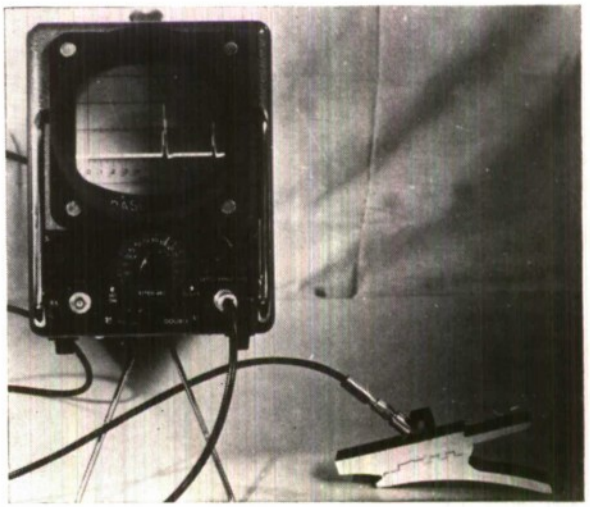

FIG. 8.

Ultrasonic Inspection of Torpedo Windows[3]

The transducer window is a vital component of the torpedo homing system and since each window is an individual rubber moulding, one hundred per cent routine non-destructive testing is essential. The development work on the test method is described in the reference and since 1962 over 2,000 components have been so tested. The specification requires the components to be ultrasonically scanned at 600 ± 50 Kc/sec., under water, free from trapped air and foreign material. The transmission loss at 27°C. should not exceed 15 ± 2 dB and the velocity of sound is to be 1500 ± 100 meters/sec. at 27°C.

In addition, at the suggestion of the laboratory, a detailed scan of the transducer pocket area was introduced to ensure freedom from internal defects.

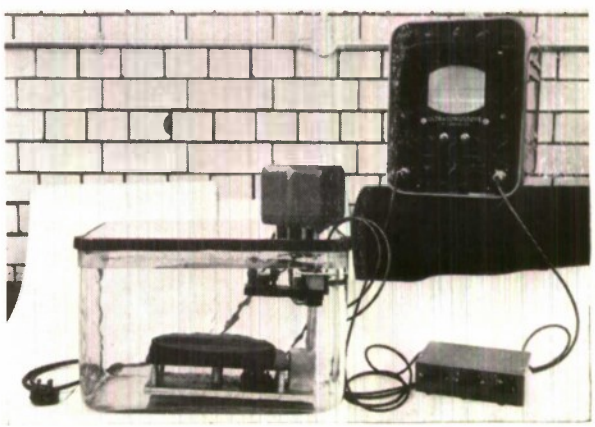

FIG. 9.

Equipment

The method uses a modified standard flaw detector plus a calibrated matched attenuator and the sample is located in a test jig comprising adjustable waterproof probe

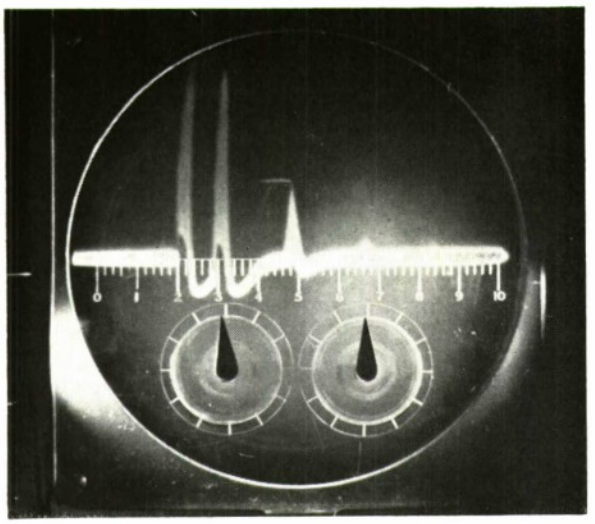

FIG. 10.

holders and means for sensitive calibrated adjustment of the probe spacings. The whole is immersed in a water tank with immersion heaters and thermostats. The first working arrangement is shown in Fig. 9. An improved set-up, suitable for non-laboratory use, is in the course of manufacture.

Technique for Measurement of Transmission Loss

Samples are brought to the correct working temperature of 27°C by immersion in the water bath for approximately one hour. The probe gap is pre-set to 4·0 in. and the depth range on the instrument is adjusted so that a number of successive echo peaks are displayed on the screen. The stepped attenuator is set to at least 45 dB and the gain control adjusted so that the second echo peak is 1·0 in. high. Fig. 10 shows the Cathode Ray tube trace consisting of a transmission pulse on the left, followed by a peak which signifies the arrival of the pulse at the receiving crystal, after a water traverse of 4·0 in. The succeeding peaks show twice the spacing owing to the transit time interval from the receiver to the transmitter and back. When the sample is interposed between the probes (care having been taken to remove any bubble from the surface) a reduction in the signal height occurs and the attenuator is adjusted to restore the second echo peak to its original height. The difference in attenuator readings represent the attenuation caused by three transits of the ultrasonic energy through the rubber. Since the attenuator is calibrated in 1 dB unit steps, it is possible to measure the attenuation, per transit, to 1/3 dB.

The amount of energy reflected from the water-to-rubber interface was calculated using the equation below. Assuming perfect wetting and ignoring interference effects, beam spread, attenuation and field effects the real value of the reflection coefficient R, is given by

$$R=\frac{W_R}{W_I}=\frac{(Z_{water}-Z_{rubber})^2}{(Z_{water}+Z_{rubber})^2}$$

Where W_R = Reflected intensity
W_I = Incident intensity
Z_{water} = Acoustic impedance of water (velocity × density)
Z_{rubber} = Acoustic impedance of rubber (velocity × density)

For a water-to-rubber interface, in which the velocities of sound in each medium are approximately equal (1490 metre/sec.) and the density of the rubber is 1·3 gramme per cc, the above equation shows the reflection coefficient to be 0·017 which corresponds with a loss of only 0·074 dB for each interface. This agreed with experiments in which the overall loss through samples of good material may be as low as 2-3 dB, and the loss due to multiple pieces agreed closely with that for a single equivalent thickness.

Measurement of Sound Velocity in the Rubber

Measurement of the precise velocity is conveniently obtained by direct substitution of the rubber for part of the water in an adjustable water gap, which is initially set to double the thickness of the sample. A pulse envelope containing a large number of discrete frequency nodes is obtained with water only in the gap and on substitution of the rubber, the interference between the frequency nodes on the transmitter pulse and those on the received pulse is annulled by fine measured adjustment of the probe gap.

The velocity of sound in the sample is obtained: —

$$\text{Velocity}_{rubber}=\frac{\text{Velocity}_{water}\times\text{Sample Thickness}}{\text{Sample thickness}\pm\text{Amount of probe shift}}$$

For ease of operation, tolerance marks are incorporated on the probe shift scale. Generally the amount of probe shift is negligible since only those samples of incorrect composition or improper cure will show significant velocity deviations. A velocity change of 2% is easily detected by this method.

Ultrasonic Flaw Detection Scan

This scan is carried out with the probes set at a distance of 4·0 in. apart, the complete area of the transducer window is covered by scanning along parallel lines. Any abrupt changes in signal amplitude are noted. These normally signify defects and are further explored.

Fig. 11 shows a section of a sample containing fine porosity which caused a transmission loss of greater than 40 dB. Fig. 12 shows an example of a massive delamination which caused a complete loss of signal.

The apparatus has also been used successfully to detect internal porosity and undercure in flexible rubber couplings (Fig. 13).

FIG. 11. Sample containing fine porosity.

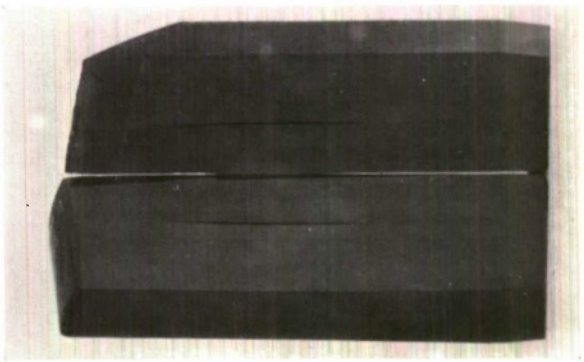

FIG. 12. Delamination in a sample.

FIG. 13. Porosity and undercure.

Detection of Air Bubbles in a Viscous Engine Damper Model Using an Ultrasonic Method[4]

A method was required for the detection of air bubbles in the silicone fluid damping medium (Viscosity 200,000 C Stokes) contained in Submarine Engine Viscous Dampers. Ultrasonic examination offered prospects of a useful inspection method and accordingly a series of experiments was set up. Two basic techniques, reflection and damping were tried but the latter was discarded at an early stage. The use of a through transmission method was precluded since in practice it would be possible to apply probes to only one side of the fluid gap, the ultrasonic beam passing through a 1·0 in. thick outer steel wall before traversing the thin (~0·02 in.) fluid layer between the case and the inner component flywheel.

Reflection Technique

Fig. 14 shows the interfaces and possible echoes in the case of a flat model. From the basic formula (used previously for water-to-rubber), the reflection coefficient R for the first steel-to-oil interface, is calculated to be 0·93, *i.e.* 93% of the incident energy is reflected and the maximum possible transmitted intensity, T=6·8%.

The transmitted energy is divided at interface 2 and again on return to interface 1. The maximum intensity of the beam finally arriving back at the top steel surface is therefore 0·43% of the incident intensity. Although a further loss occurs in the transducer coupling, the remaining energy can be readily detected with a modern ultrasonic flaw detector.

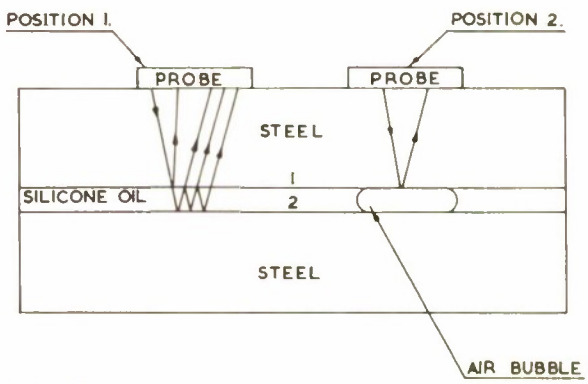

FIG. 14.

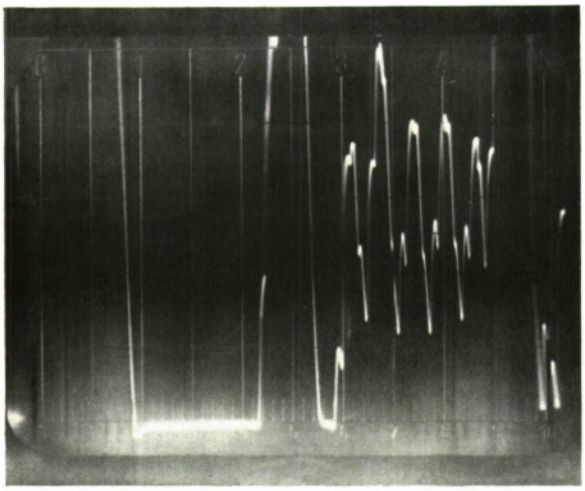

FIG. 15.

The technique was investigated using a simple model with bubbles deliberately retained within flat washers. A standard ultrasonic flaw detector with a variety of probes operating at set frequencies in the range of 1 to 6 Mc/s was employed and optimum results were obtained using a 6 Mc/s, 10 mm. diameter probe. With the instrument calibrated for steel, it was calculated that the fluid thickness of 0·014 in., as used in the model, should produce reflections at approximately 2·5 mm. scale intervals after the first steel back echo.

Fig. 15 shows the trace obtained when the silicone fluid is continuous. The series of smaller peaks which follow the first back echo from the steel are multiple reflections from the liquid/steel interfaces. To confirm that the echoes were genuine, the fluid thickness was increased to 0·028 in. by doubling the separating gasket. Repetition echoes from the second fluid to steel interface were again obtained and as expected the intervals were doubled, *i.e.* from 2·5 mm. to 5 mm.

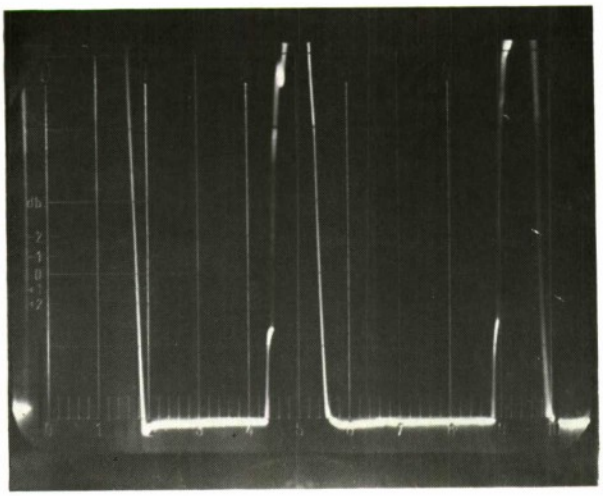

FIG. 16.

Fig. 16 shows the trace from an unsatisfactory sample containing an air bubble of 0·55 in. diameter and with careful scanning it was found possible to detect individual artificial bubbles of 0·15 in. diameter by a sharp reduction in the amplitude of the multiple echo peaks.

It was concluded that the reflection technique was basically suitable for the detection of voids and bubbles in the liquid film between flat surfaces. A necessary proviso of course is that the outer steel member of the assembly must be free from significant internal discontinuities. On curved surfaces, in order to minimise the reduction in coupling and beam dispersion, it would probably be necessary to refine the method, for example by using a transducer crystal specially matched to the radius of curvature of the damper body. Coupling would also be improved by mounting the probe on a small carriage and providing a continuous feed of fluid couplant.

Ultrasonic Wall Thickness Measurements

One example of the application of ultrasonics to the measurement of wall thickness from one side only is in the determination of residual metal thickness of A/S Mortar Barrels. The service life of these weapons has probably been extended beyond the original estimate of the designer and loss of strength by corrosion may be significant.

Corrosion is often most severe on the outer surfaces of the inner barrels, remote from the muzzle. In the Mk. 10 Mortar these areas are enclosed by the outer gas chamber and in the Mk. 3 Mortar by the casing. In each case, the area is inaccessible to normal gauging methods. The method selected as most feasible was an ultrasonic pulse echo technique using a fast time base and with the probe applied to the relatively smooth inside surface of the barrel. This system has the following advantages:—

(i) Direct reading.

(ii) Freedom from ambiguity which can occur with multiple echo techniques.

(iii) Not invalidated by severe pitting corrosion and/or adherent scale on the far surfaces. Resonance systems fail on such surfaces.

(iv) A modern flaw detector can be used and hence only one instrument needs to be provisioned for both flaw detection and thickness measurement. In this instance Ultrasonoscope Mk. 5 instruments were already available in H.M. Dockyards.

Principle

The ultrasonic pulse echo technique uses very short (micro second) pulses of high frequency sound energy which are transmitted through the material and reflected from the back surface of the test area. The pulse transit time is proportional to thickness and depends upon the velocity of sound in the material. Provided the calibration of the instrument time base is made on standard thicknesses of the material to be tested, the instrument can be made direct reading. In the initial proving tests, the ultrasonic probe was applied manually to a section of a scrapped barrel. A series of micrometer thickness measurements were made on the barrel and the outer (normally non-accessible) test areas were drilled to simulate deep corrosion pits. In addition a number of flat and curved test blocks, also containing simulated corrosion pits, was prepared.

The results of the preliminary test were sufficiently encouraging to justify the development of a probe positioning jig suitable for operation in a Depot or Dockyard and which would enable all of the internal surface of the barrel to be scanned. Opportunity was taken to incorporate the following improvements:—

(a) A combined double PZT crystal compressional wave probe to steepen the leading edge of the echo pulse together with a perspex delay to completely remove the transmission pulse from the measuring range on the C.R.O. screen.

(b) A spring loaded probe holder with a contoured PTFE stand-off skirt to resist wear and to retain the oil couplant between the probe and metal surface. The level of the probe surface is pre-set to 0·002 in. below the stand-off skirt using a feeler gauge.

(c) A capstan type of operating rod with length and angular calibrations to enable the position of minimum wall thickness to be charted.

(d) Pressurised feed of couplant to the probe holder.

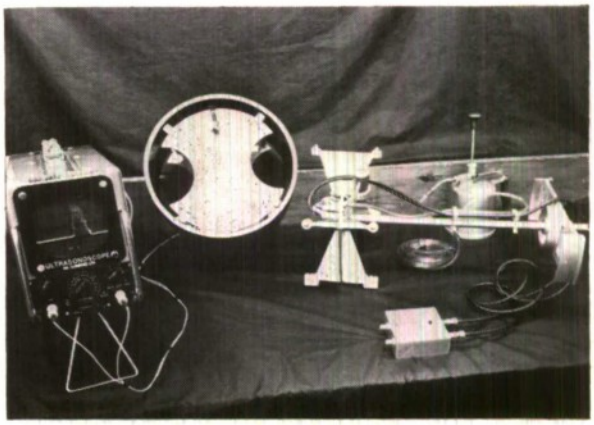

FIG. 17. Production equipment and prototype jig positioned in a section of barrel.

(e) A switchable reference standard to permit the calibration to be checked for zero drift and range calibration, without removing the probe from the Mortar tube.

Full scale tests of the prototype showed that the wall thickness could be measured to better than ± 0·004 in. No change in the measurement, due to wear or instrument drift, could be detected after 100 insertions and withdrawals of the jig from the test barrel. Fig. 17 shows the prototype positioned in a section of barrel and a production model ready for issue to a depot. Fig. 18 shows the details of the probe and holder.

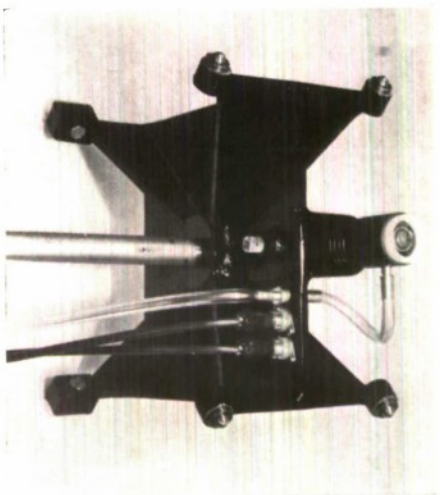

FIG. 18. Probe and holder.

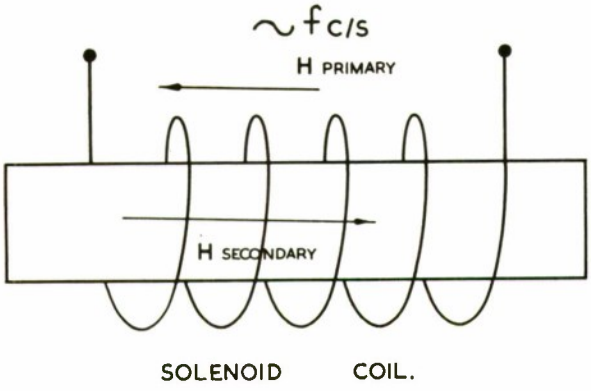

FIG. 19(a).

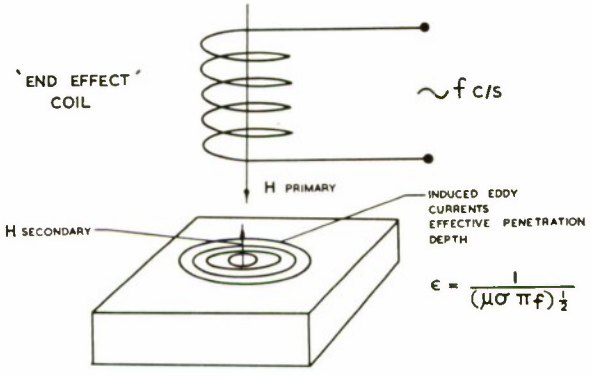

FIG. 19(b). Test coil arrangements.
H Primary = Primary field in absence of sample.
H Secondary = Field due to eddy currents in sample.
Sample is effectively a short circuited single turn secondary winding.

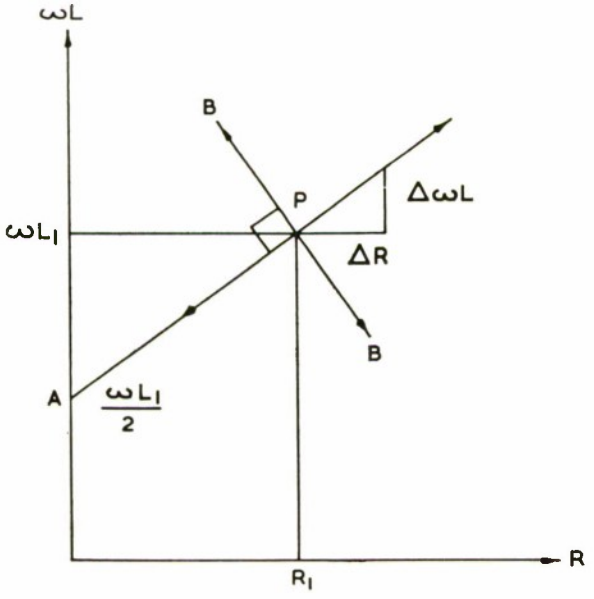

FIG. 20.

Eddy Current Methods

The instruments may be roughly sub-divided according to the principle factor to which they respond, *e.g.*, loss, impedance, reactance, phase change or frequency. Some instruments use a combination of the above factors and care must be exercised in the interpretation of results, particularly when two or more of the basic physical properties of the sample interact, for example geometry, conductivity, permeability, coercivity. However, provided that suitable standards are available, it is usually possible by selection of the frequency range, method and level of excitation, *etc.*, to lower the sensitivity to interfering variables and thereby to avoid inversion effects and ambiguities. Many forms of energisation and coil arrangements are utilised depending on the particular inspection problem. For example in surface crack detection of tubes and rods a common system employs differentially matched coils in a connected bridge circuit. The bridge is initially balanced with both coils positioned on sound material and becomes unbalanced when a crack comes within the field of one coil.

The Core-Loss Comparator[5]

This is a general purpose instrument in use in Bragg Laboratory and various Naval Ordnance Inspection fields and is essentially a loss sensitive type. The circuit of the instrument is basically that of a Kallitron negative resistance oscillator. Self-excited oscillations are produced because the tuned circuit of the test coil is shunted by the negative resistance of the oscillator. The coil is effectively a tuned circuit of capacitance C_o and self-inductance L_o and the circuit oscillates at the natural frequency, f=

$$\frac{1}{2\pi\sqrt{L_oC_o}}$$ (for coils of medium or high Q).

The range of operating frequencies of any particular coil can be varied downwards from the natural frequency by switching in shunt capacitors.

In operation the test coil field links with a metal sample (see Figs. 19a and b). Energy losses occur which affect the 'Q' of the coil and hence the strength of the oscillation, which is in turn indicated by a meter reading. At low frequencies, in the case of ferromagnetic materials, the losses are mainly due to magnetic hysteresis and at high frequencies energy losses are chiefly resistive eddy current losses. Variations of coil impedance can be represented by an impedance vector diagram, as in Fig. 20. Point 'P' is determined by the 'empty coil' impedance. Varia-

tions in inductive reactance and A.C. resistance, ωL and R respectively, which together produce a resultant parallel to AP, will not be indicated since the amplitude is constant if:—

$$\frac{L + \Delta L}{R + \Delta R} = \frac{L}{R}$$

The most sensitive direction is that parallel to BB. In the case of impedance changes due to conductivity, permeability or geometry variations, the vector is divided into two components. Only the component parallel to the sensitive direction BB will cause a change in indication and the component parallel to AB has no effect on the reading.

Some recent applications of the Core-Loss method include the segregation of faulty rifle detent springs, sorting of 5% chromium-molybdenum steel super heater tubes from otherwise identical stock of 1% chromium-molybdenum steel tubes and the measurement of Sif-bronze coatings on a fuze component. The last required modification to the basic circuitry of the instrument and is described in more detail. At the appropriate inspection stage the sub-assembly consists of a hollow conical steel housing, part of the outer surface of which carries a coating of sprayed alumina on top of which is a similar but narrower track of sprayed Sif-bronze. Each coating is required to be certified as between 0·008 in. and 0·015 in. thick and because of the mass production procedures involved, it was essential to measure both coatings at the same inspection. The method developed comprises two stages:—

(a) Measurement of the total thickness (both coatings) by a commercial magnetic layer thickness gauge, range 0·035 in. which was specially calibrated to take account of the particular curvature of the steel housing. A simple jig (see Fig. 21), was used to ensure accurate positioning of the ball end of the probe with respect to the test surface and it was found necessary to keep the contact of the ball within $\pm 0{\cdot}1$ in. of the centre of the coated track, so as to avoid errors due to the raised steps of the steel at the side of the track.

(b) Measurement of the Sif-bronze by an eddy current Core-loss method which depends on the average local thickness of the Sif-bronze conductor beneath the probe and the electric conductivity of the test area of the Sif-bronze. Small errors due to changes of porosity or varied compositions of the Sif-bronze cannot be avoided. The probe consists of a transformer type of 'end effect' coil with a ferrite core. Interfering effects due to varying proximity of the steel base were nullified by resistive loading of the secondary of the transformer winding and by keeping the frequency of the coil sufficiently high (approximately 100 Kc/s), to limit the penetration of eddy currents into the steel whilst still permitting full penetration of the Sif-bronze. The measurement is affected by proximity at the edge of the sprayed track and it was found necessary to locate the centre of the coil within the middle $\frac{1}{8}$ in. of the track. For this purpose a small guiding shoe was manufactured in Araldite. The measuring circuit was specially modified to provide a meter reading which was sensibly linear with thickness of coating and the scale was calibrated in mils. of Sif-bronze. For routine operation, the calibration is set using two standards and the instrument is then used as a direct reading thickness gauge.

Thermal Methods[6]

These methods depend on thermo-electric E.M.F.'s but since in many applications a heated contact probe is applied to the unknown sample, variations in thermal conductivity may contribute to the overall measurement. The methods have been intensively investigated at Bragg Laboratory, with special reference to sorting and to determination of coating thicknesses.

Sorting

The method is most reliable when it is known that only one element at a time is varied in a range of chemical compositions. Obviously, it is also necessary that the varied element produces a significant and unambiguous change in thermo-electric output. Recent examples of the successful applications of thermo-electric sorting include confirmatory tests during the sorting of super heater tubes in 5% chromium, 1% molybdenum steel from 1% chromium, molybdenum steel and sorting of finished components in tool steels of differing silicon contents.

Measurement of Plating Thickness

The thermal method is successful for nickel plating on ferritic steel where magnetic methods are unsatisfactory and was espec-

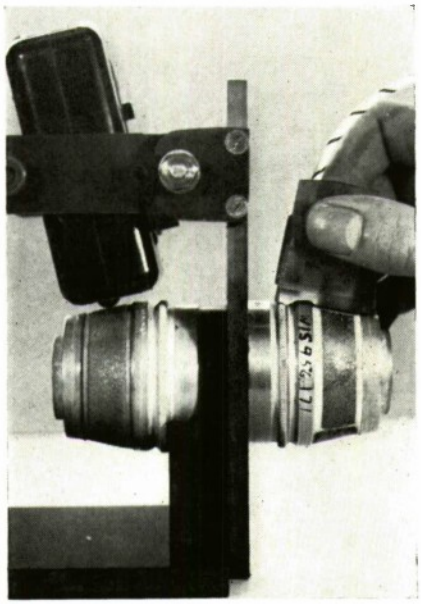

FIG. 21.

ially successful in the case of hard chromium plating on bearing components in austenitic stainless steel.

Methods based on magnetic, electromagnetic and eddy current effects were not applicable due to the low permeability of the stainless steel substrate and to the electrical conductivity of the chromium being variable but generally similar to that of the stainless steel.

A thermo-e.m.f. probe was used in such a way that the nett thermo-e.m.f. due to the temperature drop across the coating was a measure of the coating thickness.

The probe was a miniature soldering iron which could accept a number of different bits as electrodes. The heater of the iron was fed from a constant voltage source and the bit was lagged so that stray heat losses were constant and small compared with the contact loss to the specimen. Consistent loading was achieved by a bench drill press with a fixed weight on the operator arm, and contact was made for a fixed time of ten seconds before reading the thermo-electric output on a galvanometer.

The method was calibrated by direct measurement of sectioned components and by careful control of the variables the accuracy of measurement of the thickness of chromium was maintained within $\pm 5\%$ in the range 0·003 - 0·005 in.

Conclusion

The examples which have been detailed were selected to provide a picture of the diversity of non-destructive testing methods employed at Bragg Laboratory. Because of this diversity and the short term nature of many requirements it has not been practicable to exploit some of the more sophisticated techniques, for example, ultrasonic frequency analysis 'C' scan methods using facsimile recorders, ultrasonic imaging, micro-wave transmission, *etc.*, which require high capital investment and can only be justified by long runs, for example by a specialist Contractor. Nevertheless there is considerable scope for ingenuity in adapting the basic principles to specific problems.

In the future, the responsibility for the quality of new manufacture by main Contractors will be increasingly placed with the Contractor and consequently the in-house non-destructive testing function may tend to concentrate more on certifying the adequacy of the Contractor's test methods and establishing the acceptance standards at the correct level. In this field the integration of the Non-Destructive Testing and Metallurgical groups at Bragg Laboratory has shown to a great advantage. This relatively unglamorous field is probably the most talked about but most neglected of all facets of N.D.T.

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JOURNAL OF THE

ROYAL NAVAL SCIENTIFIC SERVICE

VOLUME 22

1967

RESTRICTED

SOLID STATE DEVICES RESEARCH CONFERENCE, 1967

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The Solid State Devices Research Conference is sponsored by the I.E.E.E. and is held in June each year. The purpose of the conference is to provide an opportunity for research workers in the field of solid state devices to exchange information and ideas in an informal atmosphere. To permit maximum freedom of expression and to encourage the presentation of incomplete and tentative results, preprints or abstracts of talks are not made available, and photographing of slides and verbatim recording of talks are not permitted. As a result of these limitations the meeting has become the best solid state devices conference in an overcrowded conference year book, and has often been the forum for the announcement of a new effect or device.

Against this background, this year's meeting was disappointing, papers being of a consolidatory rather than innovatory nature. Nevertheless, the details which speakers were prepared to divulge made the journey well worth while.

The meeting was held in the University of California at Santa Barbara, about 100 miles north of Los Angeles. The campus is very new and is still not complete. It is in a wonderful situation on a cliff top overlooking the Pacific Ocean. The electrical engineering department is expected to be overwhelmed with applications for employment in the months after the conference.

Picking out the important papers in a conference of this sort must, to some extent, depend on one's own interests, but there were several talks which announced outstanding new advances in performances, or elegant solutions to important technological problems, and some of these may be of general interest.

Prager, Chang and Weisbrod of R.C.A. have obtained some very high efficiencies in using the avalanche breakdown of silicon diodes placed in a suitable r.f. cavity to generate near-microwave frequencies. Most work of this kind has been in the S and X bands, where the best result so far has been Bell's 2·7 watts C.W. at 13·8 GHz with an efficiency of 10·2%[1] R.C.A. have been interested in rather lower frequencies, around L band, where they have obtained 180 watts (pulsed) at 725 MHz with an efficiency of 60%. The reason for this high figure is connected with the fact that the diodes are being used well below their transit-time frequency, so that to obtain a similar efficiency at a much higher frequency is not straightforward. Nevertheless, such an efficiency is considerably higher than has been reported for Gunn-type oscillators.

Bell Telephone Laboratory have been working for some time on a suitable vidicon tube for a "visionphone." Such a tube, since it is to be installed in public places, must be idiotproof. For example, it must not suffer if pointed directly at the sun. Conventional vidicons will certainly not withstand such treatment, and so Bell have developed a silicon diode array which acts as the target in a camera tube. The array has the further advantage over the conventional target in that it has no photoconductive lag, has much higher sensitivity and wider spectral response, and will withstand

much higher temperatures during fabrication, thus enabling the tube to be baked out more effectively before sealing. Constructional details have been described by Bell[2]. Basically the target is an array of 540 by 540 reverse biased diodes on a centimetre square chip of silicon. The diodes, which are planar in construction, are 8 microns in diameter. One contact to the diodes is common and the other is by means of a scanned electron beam. In normal operation, the electron beam, the diameter of which is larger than that of a single diode, periodically charges the diodes down to cathode (ground) potential while the potential of the bulk material is held at about 10 volts. The incident light associated with the image is absorbed in the bulk of the silicon, creating electron-hole pairs. The minority carriers then diffuse to the depletion layer of the nearest diode, discharging the diode by an amount proportional to the light intensity. The recharging of the diodes by the scanning beam creates the video signal. The difficulty in making arrays of the kind in the past has been one of reducing the diode leakage current. Unless it is either small, or spacial variations of it are small, compared with the signal, a very poor quality picture will result. Further, the diode capacity, which is very small (about 5.10^{-3} pf) must not be discharged by the leakage current during a frame time (1/30 second). This means that the leakage must be less than 5.10^{-13} amps per diode, and it is a considerable technological feat that they have achieved this figure consistently.

The search for ever-purer materials for device fabrication continues, and Hewlett Packard have made some very high quality gallium arsenide by the liquid phase epitaxy method. In this method, a solution of GaAs in gallium is poured onto a GaAs substrate at elevated temperature and allowed to cool. GaAs then grows out of solution epitaxially on the substrate. The lowest doping level observed by the authors is 8×12^{12} per cc, which is lower than previously reported figures by an order of magnitude or so. This success is due to the prevention of contamination of the deposited layer by the substrate. The authors were unable to explain why this was so.

There were two papers on high efficiency electroluminescent p-n junctions. The widespread use of such devices has so far been limited by poor conversion efficiencies of less than 0·1%. Bell have made Gallium Phosphide lamps with over 1% efficiency reproducibly. The junction was formed by liquid phase epitaxy and the secret of their success was claimed to be an anneal for 24 hours at 700°C, this step improving the efficiency by up to an order of magnitude. The GaP was prepared in pyrolytic boron nitride boats and liners and this, too, was stated to be important.

I.B.M. reported even higher efficiencies using GaAlAs p-n junctions. Using a 60% Ga, 40% Al constitution, diodes had shown efficiencies of 3·3% when coated with an anti-reflection coating to enable as much light as possible to leave the junction. Unlike the GaP lamps above, which emit at 6900 Å, the radiation from these junctions is further into the infra red (7200 Å) and is not therefore of great commercial interest, since the eye is hardly sensitive at this wavelength. Nevertheless by varying the ratio of Ga to Al in the compound the wavelength can be changed and there is hope of reasonable efficiency into the visible spectrum.

This conference was run at the same time as the I.E.E.E. Electron Devices Meeting in Montreal. Several papers were common to both meetings, and as the subjects of these conferences are now almost identical, it is intended to run them consecutively next year, at Boulder, Colorado. Whether anyone could usefully benefit from six fully packed days of conference is another matter.

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MODERN CHEMICAL ANALYSIS

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Introduction

Chemical analysis has been defined as "an attempt to determine with the required accuracy the proportions in which any or all of the components of a mixture or compound are present". In the early days of chemical analysis a component was almost always an element though often expressed as a basic or acidic oxide, and the history of analysis has been that of the gradual development of the concept of a component. As the idea of a component has become more sophisticated, chemistry alone has proved inadequate, and today in many laboratories a larger proportion of determinations are physico-chemical. The need for faster and more accurate analysis, as a result of technological progress in industry, has profoundly influenced ideas on both chemical and physical procedures. Furthermore, industry has become much less empirical and more exacting than it was.

The early history of chemical analysis is a story in its own right and we pass on to consider the impact physical chemistry has had on the science of analytical chemistry. Physical chemistry was applied to analytical problems about 1870. In systemising and explaining the mass of facts huddled together under the headings 'organic' and 'inorganic' chemistry a new understanding was reached. Mainly responsible for this change were Mendeléeff, Faraday, Kohlrausch, Ostwald, Arrhenius and Nernst.

Between, say, 1920 and 1945 chemical analysis was enjoying a sort of renaissance. Introduction of new reagents and a better understanding of old reactions enlarged the scope of inorganic analysis, and freed it from the too rigid framework of 'systematic analysis' and the 'group tables'. In organic analysis the success of Pregl's micro-analytical methods was little short of revolutionary. This new technique gave the analyst three great advantages; he could analyse much smaller samples, he could work much quicker, and his analysis on three or four milligrams was more accurate than was possible by the older methods. As a result there was a general tendency to work on a smaller scale. This trend is much in evidence today.

Again physical chemistry was leading to a more scientific approach, while improvements in physical instruments, often developed for other industries, enabled measurements to be easily made of properties not previously accessible. Since about 1940, analytical chemistry has adopted three new kinds of instruments. Classical wet methods have in part been made automatic. Much faster, more sensitive instrumental methods that employ physical rather than chemical effects have come into widespread and increasing use. Also the signals from both approaches may now be automatically recorded in graphic or digital form.

Basic Principles of Analysis

All analytical methods, wet or instrumental, measure some unique effect caused in a structure by its interaction with one or more forms of energy. These effects occur at different levels of atomic and molecular structure. For instance, melting and freezing processes involve forces between the molecules of substances. Effects such as thermal conductivity and the emission of infra-red spectra, occur at the molecular level, as the molecules rotate and vibrate. On the other hand, chemical reactions involve valence electrons, while the emission of X-rays comes from electron jumps between inner orbits of the atom. There are also nuclear effects, such as magnetic resonance, and also intra-nucleonic effects which are exploited in

radio-chemical analysis. One way to index analytical methods would be in terms of these structural levels.

Also a way to systemize actual analytical procedures would be according to the number and type of step required to perform an analysis. These are basically three in number.

(i) Complete wet chemical separation of a component or components of the material and final essay of these by either classical methods or a simple instrumental technique.

(ii) Preliminary chemical separation or treatment of sample with the actual analysis performed using an instrumental method.

(iii) Material not subject to any treatment prior to analysis by purely instrumental means.

Some analytical procedures would not, of course, fit any one of these categories exactly.

The subject of separation of components by chemical means is vast and no attempt is made here to discuss this topic in detail. Briefly, when the mixture is homogeneous, separation calls for methods exploiting subtle molecular differences. Many such methods have been developed in recent years. Certain methods operate by adding heat or chemicals to form a second phase rich in the desired component as instanced in zone refining, solvent extraction, ion-exchange and chromatographic procedures. Others use either barriers or concentration gradients within the single phase to make the separation, as in molecular sieving, electrodialysis, electrophoresis and thermal diffusion. In either case, most of the methods exploit differences in phase equilibria.

Methods in Analytical Chemistry

A typical wet analysis can be time-consuming. Firstly, as in all chemical analyses, instrumental as well as wet, a representative sample must be obtained. This is a task not necessarily easy when the unknown is not a gas. Secondly, it must be prepared for analysis, perhaps by removing components that are apt to interfere, or by changing its chemical state.

Analysis of materials can be elemental, measuring the amount of elements, as in most inorganic analyses, or it can be functional, measuring the amounts of compounds, radicals, side-chains and other functional groups, as in most organic analyses. Each kind of analysis has its own routine strategies. For instance, it may be necessary first to establish the qualitative nature of the material by chemical or physical tests. If chemical the sample will be prepared in a form which will allow it to be dissolved in an appropriate reagent to then be subjected to a working scheme of analysis. Quantitative analysis can follow in which the various required components are assayed using an accurately weighed sample.

If volumetric, the amount of a substance is determined by adding a known quantity of a reagent, called a titrant, required to react with all of the unknown, according to the appropriate reaction formula. In gravimetric analysis, a selected reagent is added to a solution of the sample to form a reaction product which is then isolated, purified and weighed. Thus the classical tools for wet chemical analysis are the volumetric flask for diluting a sample to a known concentration; a calibrated burette for measuring and dispensing the reagent; a pipette for transferring exact amounts of liquid, a reaction flask and an accurate balance. They also include the standard reagents and indicators, and the hand and eye of the analyst.

As mentioned earlier, analytical methods can be indexed in terms of structural levels and this provides a spring-board for their discussion.

Substances change as their temperatures change, and in characteristic ways. Thermal methods monitor these changes. Thermogravimetry measures the decreasing weight of a substance in a vacuum, or in an atmosphere either inert or its own, as it is progressively heated in an automatic recording thermo-balance. The plotted curves are characteristic of the substances present. Another useful thermal method is cryometry. Here the freezing curve of the sample is plotted, in particular the freezing point, and so is a good method for testing the purity of a substance whose identity is known. Such methods as above measure either amounts of heat or transition temperatures.

The thermal conductivity of a substance has been made the basis for a quantitative analytical method known as gas chromatography. This technique has attained considerable importance in recent years, particularly in the field of organic chemistry. A gas chromatograph isolates and measures the volatile fractions of a mixture of elements or of compounds. Only the quantitative function is based on thermal conductivity, the detection devices being heated wires or thermistors that signal the amount and duration of the cooling effect upon them of each substance that streams by. The source of these substances is the chromatograph column, which is packed with a material called the sorbent. A sample is introduced at the column inlet, usually in a very small amount, and into a stream of carrier gas which moves it toward the detector. As the gaseous sample moves through the column, its constituents travel at different and characteristic rates, determined by their vapour pressures, solution interaction, and diffusion. As the constituents emerge, their concentration is measured as a function of time and if recorded, describes a curve called a chromatogram. Each

peak on a chromatogram signifies the passage of an isolated fraction of the sample. Therefore, from its time of emergence, height, width and area, qualitative and quantitative data can be determined and related to the original sample.

Electroanalysis can be considered as a group in its own right. Amperometric titrations, as the name suggests, measures the change in current proportional to the change in concentration of reactants and products. In potentiometric and conductimetric titrations, voltage and resistance changes are correspondingly monitored. Perhaps the widest industrial application of potentiometry is in electronic pH meters, which measure acidity with great accuracy; pH meters also find wide application in the analytical laboratory. Electrical energy is also involved with chemical reactions in the methods of coulometry and electrodeposition, wherein electrons are effectively a reagent for titration and separation respectively. In coulometry, the current is measured, in electrodeposition the reaction product is weighed. Polarographic instruments are also electroanalytical; each contains an electrolyte in which a sample is dissolved. As the applied voltage varies in a known way, the instrument plots a curve of the current that passes through the solution between a reference electrode and another electrode formed by a series of mercury drops. While it is only a poor qualitative tool, it is an excellent quantitative tool; at least for traces of elements that are electrically oxidisable or reducible. Polarography was invented in 1922 by Jaraslav Heyrovsky. Polarography is one of a group of electroanalytical techniques which are classed under the general term 'voltammetry', since all of them monitor current-time-potential relationships at electrodes immersed in electrolytic solutions. Examples of these techniques would be constant-potential voltammetry and chrono-potentiometry.

A large single class of new analytical instruments include those that employ electromagnetic radiation to interact with the sample. As a group they are called optical, even though visible radiation is a narrow band indeed in the spectrum of wavelengths used, which run from the short wavelengths of gamma and X-rays to the longer wavelengths of microwaves. The energy of electromagnetic radiation varies inversely with wavelength and the shortest wavelengths have the highest energy. Hence, it is possible to select radiation frequencies to interact with different levels of electron energy to yield qualitative, elemental, functional and structural data. For instance, microwaves and infra-red radiation interact with molecular vibrations or rotations and with weak interatomic bonds. Ultra-violet and visible radiations interact with strong interatomic bonds and valence electrons, X-rays with inner-shell electrons and gamma rays with atomic nuclei. Interaction of electromagnetic radiations with matter can result in the radiation being emitted, absorbed, reflected, diffracted, refracted or polarised.

The measurement of emission and absorption spectra is called spectrometry. In emission spectrometry, the sample is excited electrically in the form of an arc or spark and the resultant characteristic emission spectrum of the components is recorded either photographically or electronically using respectively a spectrograph or a direct reading spectrometer. Similar spectro-chemical techniques which exploit characteristic emission, absorption or fluorescent radiation are respectively flamephotometry, atomic absorption spectrometry and atomic fluorescence spectrometry. One relatively new spectroscopic method is X-ray fluorescence in which X-rays bombard a target made of the sample and release characteristic secondary X-radiation of those elements present in that sample. The measurement of absorption spectra is called spectrophotometry. It is especially important in organic analysis where, particularly in the infra-red region, absorption analysis proves to be a powerful tool for identifying functional groups. Spectrophotometry using light in the visible region is discussed in a later section.

It is also possible to get information about a sample's composition and structure from interactions of the nuclei and electrons in its constituent atoms with a magnetic field. The mass spectrometer ionises the sample, then sends the ions at a uniform speed through a uniform magnetic field and a perpendicular electrostatic field. All ions of identical mass-to-charge ratio are focussed into one beam. The various beams form a mass spectrum. Quantitative analysis is relatively easy to perform using a mass spectrometer or spectrograph and in many cases the sensitivities obtained outclass most other analytical techniques. Resonance methods, nuclear magnetic resonance (N.M.R.) and electron spin resonance (E.S.R.), detect the absorption of radiofrequency waves and microwave radiation respectively. In N.M.R., this is caused by nuclei with magnetic moments not equal to zero and in E.S.R. the presence of unpaired electrons, which are precessing at a resonant frequency determined by the strength of an applied magnetic field. These techniques can be made to yield analytical data.

The application of radioactive materials in chemical analysis is now widespread. 'Tracer' methods which employ radioactive materials and solutions of components of interest in analysis are in effect aids to the perfecting of analytical methods. This technique can equally be applied to many reactions of analytical significance particu-

larly when dealing with elements which, by reason of lack of sharply defined chemical reactions, are analytically 'difficult'. All radioactive substances share two properties important for analysis. Firstly, a radioisotope's rate of decay rarely affects and is never affected by its chemical environment. This is why it is possible to replace a stable atom by, or convert it into a radioactive one, and trace its fate during a chemical reaction. There are several ways in which it is possible to convert normal stable atoms into radioactive ones. This is the basis of a powerful analytical method known as neutron activation analysis. Essentially, the sample is irradiated in a neutron flux and the radioisotopes of the elements present in the material are separated and assayed using special detection apparatus. In some instances, particularly in fast neutron activation analysis, no separations are required and direct/gamma-ray spectrometry is used to determine the desired component. Since amounts of radioactive material as small as 10^{-12}g in mass can be detected, it is not surprising that this analytical technique represents, in the case of some elements, the ultimate in sensitivity.

Several other techniques not previously mentioned are being increasingly employed in general analysis. Notable examples are spectrophosphorimetry employing the phenomenon of phosphorescence and ultramicroanalysis which enables very small quantities of material to be analysed.

Chemistry or Physics ?

Is physics devouring chemistry ? Are wet chemical methods on the way out ? In the writer's opinion the answer is no, certainly not in the near future. While analytical techniques multiply, the latest methods do not necessarily replace the old ones. Despite the advantages of direct physical methods, chemical methods are still very important. Many laboratories have to cover an enormous range of determinations, either organic or inorganic, but it is only when the number of determinations of a particular kind increases that it is economic to install expensive equipment such as sophisticated spectrophotometers, X-ray fluorescence spectrometers or mass spectrographs. An even greater reason for the continued importance of chemical methods is that they are not dependent on calibration, where all the 'direct' physical methods are secondary and have to be calibrated by means of a series of analysed standards. In the organic field it is often easier to make up samples from known components, whose purity can be checked by properties such as melting point or refractive index.

At first sight it may seem that the analyst's job has been made somewhat easier with the advent of instrumental analytical techniques. If anything the opposite case is true. The analyst must depend on theory and on other men's work, and paradoxically it often seems that there is too much information. There are too many ways of doing almost every determination, too many ways often of thinking about the individual steps in the process. The modern analyst must therefore be able to think in terms of X-ray diffraction or light absorption as readily as of neutralisation or of solubility product.

Analysis at Bragg Laboratory

Many of the techniques which have been outlined are used at Bragg Laboratory and a brief description of how these are applied to the analysis of materials is given here.

The laboratory is called upon to analyse a wide range of materials including ferrous alloys, nonferrous alloys, slags, rubbers and various polymers. Instrumental techniques used at the laboratory are X-ray fluorescence spectrometry, mass spectrometry (thermal ionisation source), atomic absorption spectrometry, polarography, emission spectrography and infra-red spectrophotometry. In some cases, pre-treatment of the sample is necessary before the physical technique can be applied.

However, much wet chemistry is used in the analysis of routine samples. A great number of the procedures used employ a photometric or spectrophotometric finish. That is to say, the element or component being determined is caused to react with a reagent to form a coloured compound and the strength of this coloured solution is measured either by an absorption photometer or a spectrophotometer. Where the compound of an element is known to fluoresce under suitable conditions, the assay can be completed using a fluorimeter. In cases where a component is volatile relative to the bulk of the sample, then simple distillation procedures are used. Similarly, electrolysis of solutions of alloys is employed in those circumstances which leads to a quantitative recovery of one or more of the elements present. Ordinary volumetric and gravimetric procedures are also used in circumstances where the particular determination is relatively free from interference.

Solvent extraction, ion-exchange, combined solvent extraction-ion exchange and chromatographic separations are being applied to an increasing extent in the separation of trace amounts of elements. It is hoped that in the future, complete separation programmes will be evolved which will allow a wide range of material to be analysed, whether the component sought occurs in macro amounts or micro amounts.

TORPEDO MAGNETIC TAPE RECORDING SYSTEMS

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Introduction

For the "in water" testing and evaluation of the performance of torpedoes an exercise head is fitted in place of the warhead. The exercise head contains the equipment for recording such parameters during the run as depth, roll, pitch, elevator and rudder movements, volts, current, r.p.m., *etc.*

For reasons of reliability, simplification of analysis procedures and accuracy, it was decided that a magnetic tape recording, play back and data processing system should be developed together with a "quick look" facility, providing an analogue output for instant laboratory or shipboard analysis and calibration. To achieve this requirement three types of tape recorder have been developed,

(a) *(Series 1400)* for use in 21 in. torpedoes with 20 channels, and subsequently

(b) *(Series 800)* a miniature equivalent of (a) for use in special purpose vehicles with 10 channels, and

(c) *(Series 600)* a 20 channel miniature recorder for use in lightweight $12\frac{3}{4}$ in. diameter torpedoes.

A special feature of the above recorders is the cassette type loading enabling the recorded tape to be removed at the end of a run in its cassette and transferred bodily and plugged into a replay system. The recorder in (c) above is designed so that its cassette is small enough to be removed through a 6 in. hand hole in the exercise head leaving the hull undisturbed, this enables a "quick look" record to be obtained as soon as possible after torpedo recovery.

Recording Techniques

In the magnetic tape recording systems described below, three types of recording technique have been used.

(a) Frequency Modulation (analogue).

(b) Digital

(c) Pulse Width Modulation (analogue).

In the case of the miniature tape recorders, frequency modulation and digital techniques have been used and for the *Series 1400* recording system digital and pulse width modulation techniques have been used.

Frequency Modulation

The dependence of reproducible accuracy on the mechanical characteristics of the tape recorder itself has been one of the limiting factors of recording analogue information on tape. For many common applications (process control, data logging, flight testing, *etc.*) the basic requirement is one of high accuracy, say $\pm 1\%$ with a bandwidth of less than 50 cps. For such recording, frequency modulation techniques are commonly used. Using a single carrier frequency modulated by one information channel, a bandwidth of a few Kc/s (depending on tape speed) may be obtained. Although it is possible to achieve a total permissible error of $\pm 1\%$ with FM recording, it is by practical standards the absolute limit and the more realistic figure would be $\pm$ 2-3%.

This method of recording demands a tape system with a high degree of performance with very low "wow" and "flutter" and it is desirable that some form of compensation is introduced into the system to reduce these effects.

A further factor determining performance in an FM recording system is to provide a modulator having good linearity and stability which in turn should have some form of temperature compensation or control.

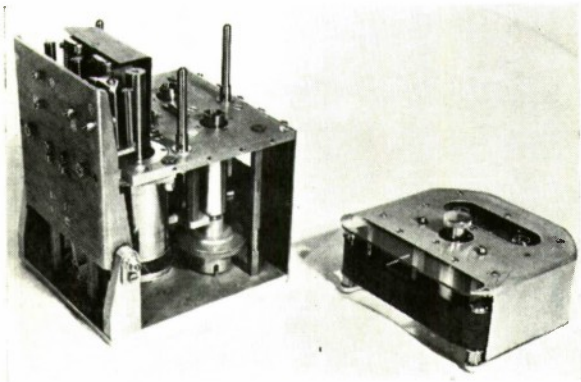

FIG. 1. Series 600 magnetic tape recorder.

Digital

Where possible a digital recording system may be used to avoid some of the problems of a frequency modulated system. Here, analogue information must be converted to a digital form by an analogue-digital converter and scanning unit.

A digital recording system is basically a sampling system, since a digital number represents one discreet value of the data signal which can only change by discreet steps. Recording serially along the tape would seriously limit the sampling rate, hence the bandwidth of the analogue signal would be restricted. For this reason parallel recording on multiple tracks is desirable for optimum performance. A clock track for replay purposes is usually necessary. The circuitry of the digital recording amplifier is a simple uncompensated switching system for operating over a wide temperature range. Wow, flutter and the mean tape speed do not affect the overall accuracy of the system.

The replay electronics consists of a high gain AC amplifier with shaping circuits followed by a digital to analogue converter for the final reproduction of the original analogue information.

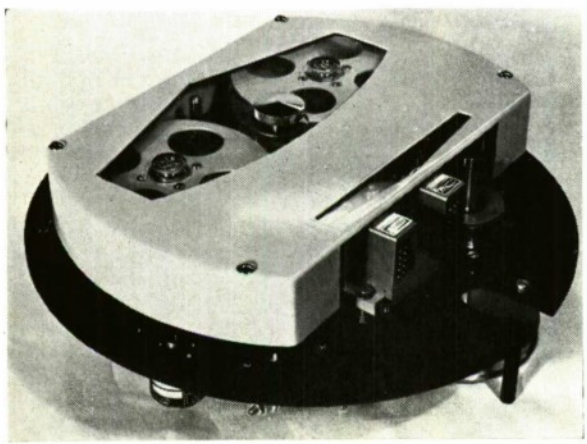

FIG. 2. Series 800 magnetic tape recorder.

A normal bandwidth of 50 c/s is obtainable. The product of maximum tape packing density and tape speed determines the maximum scanning rate and hence the bandwidth. An accuracy of $\pm 0{\cdot}2$ - $0{\cdot}5\%$ might be obtained with such a system.

Pulse Width Modulation

A pulse width modulation system has advantages over an FM system, for instance, it is insensitive to wow and flutter and mean tape speed change, in effect, the mechanical perfection of the tape recorder is exchanged for electrical perfection in the circuitry.

A bandwidth of 50 cps is easily obtained by this method. The system error in PWN should not exceed $\pm$ $0{\cdot}5\%$. For a detailed analysis of this system see Reference 1.

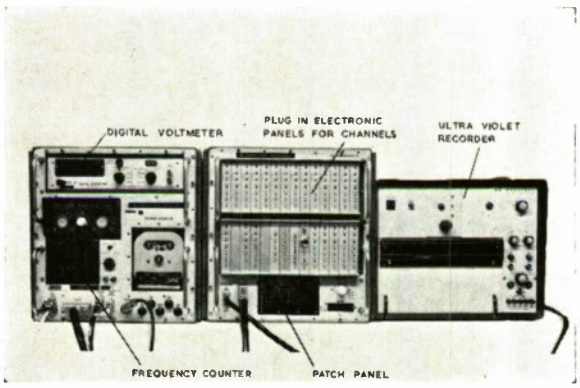

FIG. 3. Replay unit with ultra-violet recorder. Series 600.

RECORD AND ANALYSIS UNITS

The system consists of two main sections:
(a) Recording Unit
(b) Data Analysis Unit

Recording Unit

This account deals mainly with the two types of recorder for the 12·75 in. dia torpedoes although some details are given of the equipment used in the 21 in. torpedoes. An automatic data processing and reduction system is under development for use with either miniature recorder and should be available during the latter part of 1968. An automatic data processing and reduction equipment has already been developed and is in production for use with the *Series 1400* recorder (Fig. 6).

The two types of recorders for use with 12·75 in. dia torpedoes are shown in Figs. 1 and 2. Fig. 1 illustrates the recorder *Series 600* developed for use with the UK Mk 44 practice head. Fig. 2 illustrates the recorder (*Series 800*) developed for

a special purpose vehicle, and Fig. 5 shows the original recorder developed for use with the 21 in. torpedoes.

The recording channels consist of hybrid type circuits made up of integrated circuit elements mounted on thin film assemblies with discrete components. It is hoped in due course to have a fully integrated circuit type system. No built in erase function has been provided in order that the risk of erasing valid data is minimised. Brief mechanical specifications for the *Series 600, 800, 1400* recorders are as follows.

Series 600 and 800

Tape Speeds	$7\frac{1}{2}$ in., $3\frac{3}{4}$ in., $1\frac{7}{8}$ in. and 15/16 in. per second.
Tape Widths	$\frac{1}{4}$ in., $\frac{1}{2}$ in., and 1 in. (nominal).
Tape Thickness	1·0 or 1·5 mils.
Reels	Special cassette loaded.
Drive system	Open loop tape path.
Capstan drive	Synchronized motor 400 cps.
Rewind speed	90 in. per second.
Duration of recording	Series 600 at 15/16 in. per second.
Replay Time	Greater than 50 minutes using 3M 599 tape. Series 800 greater than 120 minutes using 3M 599 tape.
Length of Tape	Series 600, 300 ft. Series 800, 900 ft.
Method of Recording	Frequency modulation and digital non return to zero.
Recording and Replay Heads	SBAC or IRIG standards. Military standard 20 tracks (10 + 10 interlace) or 1 in. tape or 10 tracks (5 + 5 interlace) on $\frac{1}{2}$ in. tape.
Total Flutter	Less than 1% RMS (under vibration conditions quoted below).
Power Requirements	60 watts at 24 volts DC with DC/AC motor power inverter.

Series 1400

Tape Speed	6 in. per second.
Tape Width	1 in.
Tape Thickness	1 or 1·5 mil.
Reels	Special cassette loaded.
Drive system	Open loop tape path.
Capstan Drive	Synchronized Motor 50 cps.

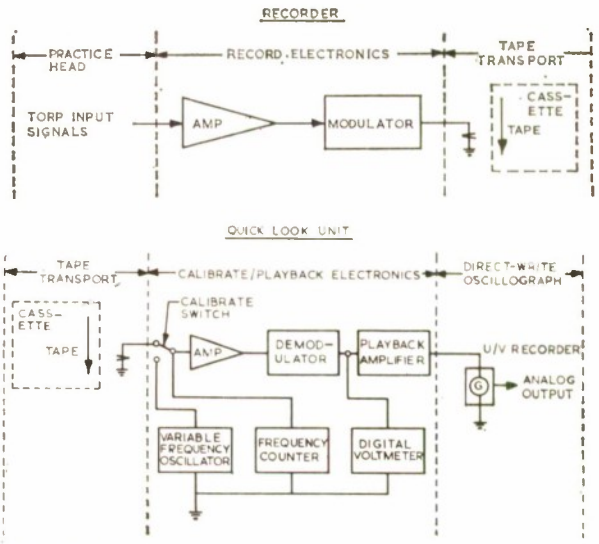

FIG. 4. Magnetic tape torpedo data system.

Duration of recording	30 minutes.
Length of Tape	900 ft.
Method of recording	Pulse width modulation and digital both non return to zero.
Recording and Replay Heads	SBAC or IRIG standards. Military standard 20 tracks (10 + 10 interlace) on 1 in. tape or 10 tracks (5 + 5 interlace) on $\frac{1}{2}$ in. tape.
Total Flutter	Less than 1% RMS (under vibration conditions quoted below).
Power Requirements	120 watts.

The electrical performance of these records follows later.

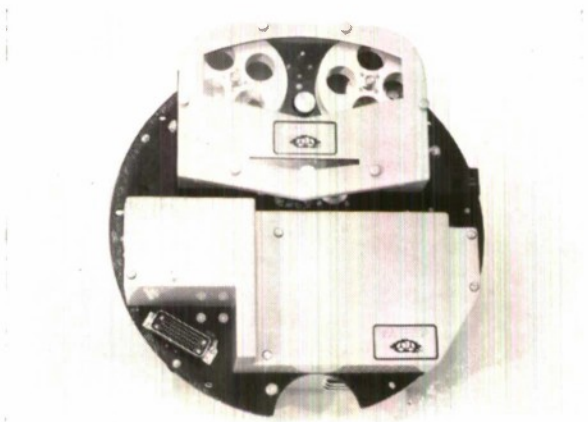

FIG. 5. Series 1400 magnetic tape recorder.

Environmental Conditions

It is an important requirement that the recorder should be capable of withstanding the environmental conditions during extremes of temperature, shock and vibration (including transport by land, sea or air), and briefly these conditions are:

Low temperature (search)	2 months at −20°C.
High temperature (search)	2 months at +60°C.
Low temperature (operational)	−29°C.
High temperature (operational)	+43°C.
Temperature Cycling	One month consisting of temperature cycling over the range +60°C to −43°C.
Vibration (survival)	15-30 cps at 0·05 in. peak to peak amplitude and 31 - 2,000 cps 5*g* peak. This includes resonance search tests.
Vibration (functional)	15 - 30 cps 0·05 in. amplitude peak to peak 31 - 150 cps at 2*g* for a period of 60 minutes over each range.
Shock	Shocks of 100*g* in each of three mutual perpendicular planes. Shock pulses of sinusoidal wave form 20 millisecs half period.

Size and Weight

The *Series 600* recorder weighs 10 lbs. and measures 6 in. × 6 in. × 9 in. complete with electronics. The *Series 800* recorder weighs 10 lbs. and measures 12 in. dia by 6 in. deep complete with electronics. The *Series 1400* recorder weighs 45 lbs. and measures 18 in. dia × 8 in. deep.

Data Analysis Unit (" quick look ") (See Fig. 3)

This unit consists basically of three sub units:
(a) Electronic Replay Unit
(b) Calibration Unit
(c) Ultra-violet Recorder Unit (10 channel).

The first two above units are packaged in standard RAE type instrument cases, the Ultra-violet recorder is a separate unit.

Electronic Replay Amplifier Unit (20 channel system)

This consists of 28 plug-in circuit modules. A complete replay channel is mounted in one module (20 channels total in the equipment shown in Fig. 3).

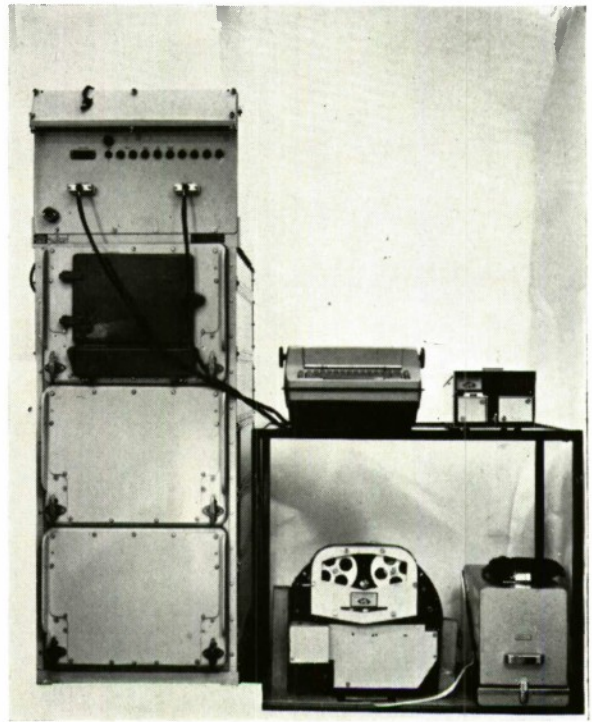

FIG. 6. Data analysis and processing equipment. Series 1400.

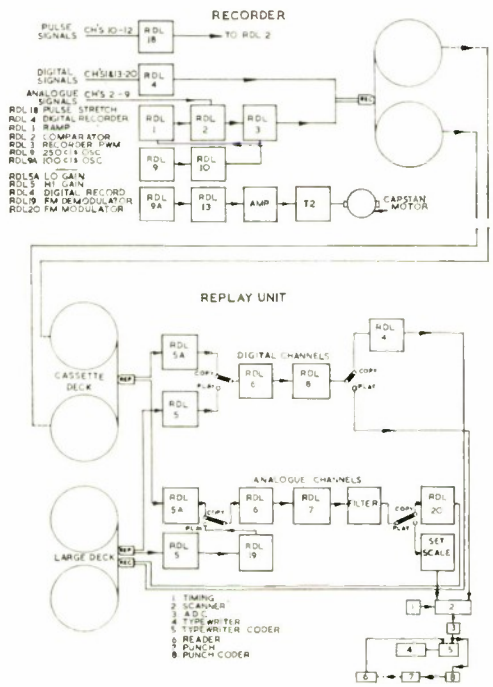

FIG. 7. Data processing equipment for use with the Series 1400 recorder.

A computer type patchboard with a 21 × 10 matrix is mounted on the front panel so that any 10 of the 20 available channels may be selected for playback on the ultra-violet recorder before feeding results into a computer on a master data analysis equipment. The calibration unit contains a control panel for the complete data analysis unit together with a digital voltmeter and frequency counter. The replay tape recorder is identical to one mounted in the weapon but with additional spooling facility necessary for the replay function.

The plug-in tape cassette removed from the weapon for replaying is plugged directly into the replay tape recorder mounted in the calibration unit and after respooling is ready for replay and subsequent analysis.

A useful feature of this equipment, where FM analogue channels are used, is the ability to rescale the recorded results. Signal off sets in the information to be recorded from transducer or other sources are usually adjusted in the setting up procedures, if not, the centre carrier frequency of an FM channel will register this off set by the appropriate frequency shift, with a resulting replay error.

To avoid this, resealing and calibration is carried out by means of calibration frequencies, which are fed to each channel in turn by means of a master channel selection switch on the front panel. The calibration frequencies are identical to those of the modulation centre carrier frequency (equivalent to zero offset signal from the transducer) and maximum/minimum deviation of the carrier (full scale excursion of the transducer output signal).

The ultra-violet recorder used to provide an analogue output trace is of standard commercial design. A brief specification for the Record/Replay is as follows.

Electrical Digital Channels

Recording Mode	Non return to zero.
Input Signal	± 3 volts peak (minimum) to ± 12 volts peak (maximum).
Input Impedance	5,600 ohms.
Output Signal	8 volts +ve going pulses.
Output Impedance	Not greater than 5,000 ohms.
Output Rise Time	Not greater than 20 micro-seconds.
Maximum Packing Density	250 BPI.

FM Channels

Input Level	2·5 volts peak for 40% deviation.
Input Impedance	Greater than 10,000 ohms (AC impedance) (current through source 0·01 mA).
Signal Source Response	1,000 ohms for specified drift.
Output Level	2 volts peak to peak for ± 40% deviation.
Output Impedance	1,000 ohms (permissible external load not less than 10,000 ohms).

Frequency Response

Speed in/sec	*Bandwith*	*Carrier*
$7\frac{1}{2}$	DC-1·5 kc/s	6 kc/s
$3\frac{3}{4}$	DC-750 cps	3 kc/s
$1\frac{7}{8}$	DC-375 cps	1·5 kc/s
15/16	DC-187 cps	750 cps

Total Harmonic Distortion	Not greater than 3%.
Signal/Noise	Dependent on bandwidth required. Typically 32db - 1·2 kc/s bandwidth.
Drift	Not greater than ± 3% in 8 hours either in 30°C range of temperature within the stated operating range with a maximum temperature gradient of 5°C per hour.

Pulse Width Modulation Channels

Input level	± 4 volts.
Input Impedance	Greater than 100,000 ohms
Source Impedance (for specified drift)	Less than 1000 ohms.
Output Level	± 1 volt.
Output Impedance	1000 ohms.
Frequency Response	0 - 10 cps. } at 6 in. sec.
Carrier Frequency	250 cps. }
Signal/Noise ratio	40 db - 100 cps bandwidth.
Drift	Less than 1% from 0°C to 40°C.

The tape recording systems described have been used successfully in torpedo trials both in the U.K. and U.S. (see Reference 2) and the *Series 600* type is now in production for use in the Royal Navy.

As mentioned previously an automatic data analysis and processing equipment has been developed for use with the *Series 1400* recorder and a block diagram of the sub units in the system are illustrated in Fig. 7.

The systems described have been developed by Recording Designs Ltd. of Camberley, Surrey, in conjunction with A.U.W.E. who are the Design Authority.

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ASYMPTOTIC GROWTH CURVES IN THE ASSESSMENT OF RADAR PERFORMANCE

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Admiralty Surface Weapons Establishment

Although increasing attention is being paid to Asymptotics as a field in mathematical analysis wherein labour-saving approximations may be found, many asymptotic methods require some theoretical knowledge of the area of application. Recently a group of functions has been used to provide approximations in Radar Information Theory which require no knowledge of underlying theory and in addition to giving a good representation of the function to be approximated, also have certain other desirable qualities. These functions—asymptotic growth functions—are more commonly employed in the fields of biology or economics and from the point of view of statistical rather than mathematical analysis. While they do not supplant the formulae of mathematical analysis they can in some cases be used to improve on them; the two approaches are, in general, complementary.

The most useful asymptotic growth curves have been the modified exponential and the logistic curve. A modified exponential curve is of form $Y = K + ab^x$. First differences of a modified exponential curve change by a constant percentage.

The logistic curve is a modified exponential in which Y has been replaced by $^1/_Y$ to give $^1/_Y = K + ab^x$. Clearly for the logistic first differences of $^1/_Y$ change by a constant percentage. The first differences of a logistic form a curve resembling a normal frequency distribution. The logistic curve is more often written

$$Y = \frac{K}{1 + 10^{a + bx}}$$

called the simple or symmetrical logistic, or more generally, $Y = K_1 + \dfrac{K_2}{1 + 10^{a + bx + cx^2}}$ called the skew or asymmetric logistic. The curve has been used extensively by Pearl and Reed to describe the growth of the population of various regions and countries; it is sometimes known as the Pearl-Reed curve and is described in some detail in the book by Croxton and Cowden [2].

In a previous article [3] an example was given of the use of logistic curves for the approximation of distributions of probability of detection of a radar target. A description was given of how by a transformation the quantity $\log (p/q)$ could be derived and how this quantity plotted against the range as a population growth model, or against the reciprocal of range as a reliability physics model, gave satisfactory approximations; $\log (p/q)$ proved to be a measure which had been termed the "plausibility" by I. J. Good in a theory of subjective probability published in 1950 [1].

Four further examples are given of the use of asymptotic growth curves. The first two consider probability of detection again and illustrate how, beneath these theoretical distributions, underlying structures can be determined by the use of asymptotic growth curves; the third illustrates a straightforward case of curve-fitting taken from an analysis of experimental sea clutter returns [9]. In the second example logistic curves were fitted by existing methods; in the third the curve was fitted with greater ease and improved precision using the plausibility. The fourth example relates the logistic curve to the cumulative standard normal curve and uses the plausibility again to represent the cumulative standard normal distribution over

much of its range, at the same time offering an alternative measure for small probabilities.

The methods used in the examples are of wide application. We have used them to describe theoretical probability distributions occurring in target detection models and for empirical curve fitting in the analysis of sea clutter reurns. Their application to the study of certain physiological aspects of diving is being considered. By their use we have been led independently to discover theoretical statistical concepts such as plausibility, weights of evidence, *etc.* and their utility [3]; this in turn has led to further implications and applications [4].

Additionally we have found these functions usually encountered in biology or economics to have some relation to reliability physics; at a molecular level an admixture of biology with reliability physics is already known [5] *et alia.* Furthermore, descriptions in the examples of successive "generations" of curves, each giving rise to further curves, are analogous to descriptions in Reference 5 of "rate-processes, linear and nonlinear which provide various interactions of chemical and physical processes" which underlie the processes of wear-out and breakdown of components.

These considerations suggest that other situations where a number of factors contribute to overall growth patterns, represented by growth curves, would be amenable to analysis by methods similar to those used for obtaining approximations in the examples. Evidence from other work [6] indicates that interactions between factors could be discerned and possibly measured—this would be particularly useful in biological experiments where closely controlled experiments are difficult to achieve.

Example 1

To obtain a simple, general formula to represent approximately the curve of cumulative probability of detection against range for any values of the range of first look R_1 and range decrement ΔR (typical curves are shown in Fig. 1), the following formula was developed, involving the use of the Normal Error Function and some simple growth curves to describe relationships between parameters $\bar{R}$ and σ *and* variables R_1 and ΔR.

$$P_c = \tfrac{1}{2}\{1 - I(u)\},\ u > 0$$
$$\tfrac{1}{2}\{1 + I(-u)\},\ u < 0$$

where $I(u) = Erf(x)$ and $x = \left|\dfrac{R - \bar{R}}{\sqrt{2}\,\sigma}\right|$;

$\bar{R}$ and σ are functions of R_1 and ΔR represented by the following relationships (shown in Fig. 2):—

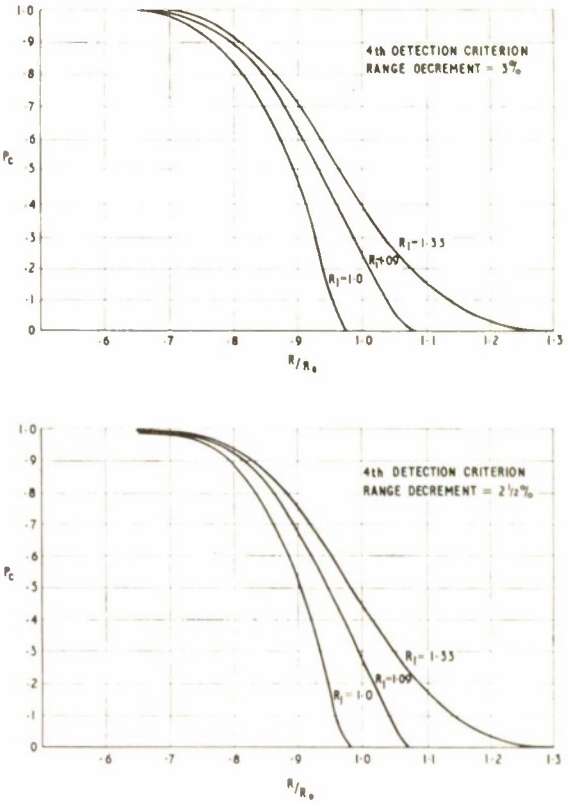

FIG. 1. Curves of cumulative probability of paint v. R/Ro.

(i) $\sqrt{2}\sigma = K_1 - ab^{\Delta R}$

(ii) $K_1 = 62{\cdot}5\ R_1^{-114}$,

(iii) $a = 49\ R_1^{-1}$,

(iv) $\bar{R} = D + C^{\Delta R}$

(v) $D = K_2\ (1 - {\cdot}01^{R1\ -1})$,

(vi) $K_2 = {\cdot}16\ (\Delta R)^{-426}$.

In relationship (v) apparent discrepancies are not significant but could be improved by the use of more sophisticated curve fitting techniques.

Example 2

In order to examine more fully the phenomena seen in the previous example and, possibly, to explore any relationships which might exist between different cases, a simpler and more accurate method of representing the distributions was required. Simple logistic curves were used. Two different cases are shown in Figs. 3 and 4 plotted on arithmetic probability paper (logistic curves on A.P. paper give straight lines). Differences between the two sets of curves, in slopes and

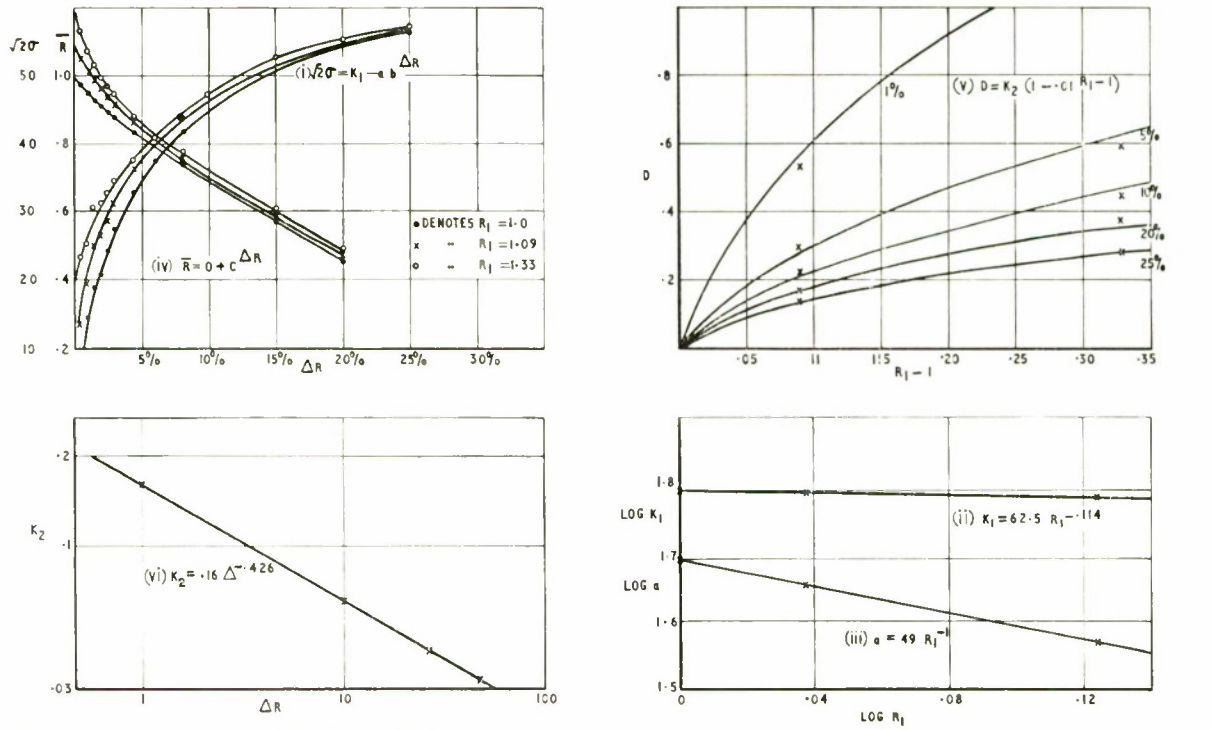

FIG. 2. Parametric relationships of Example I.

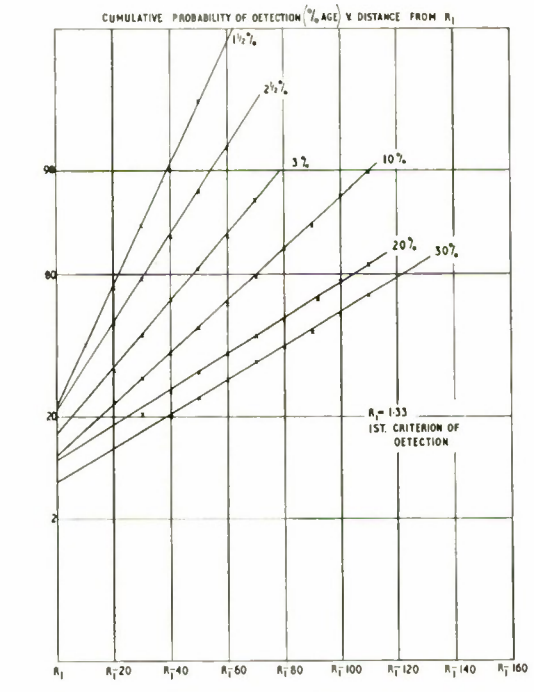

FIG. 3. Cumulative probability distribution on probability paper.

positions, are immediately obvious. Although some of the distributions could be represented better by "skewed" logistics the symmetrical logistic gives close approximations and is easier to compute.

For each simple logistic curve

$$P = \frac{1}{1+10^{a+bx}};\ x = R - R_o,\ b < 0,$$

representing a probability distribution, a and b are determined by the values of R_1 and ΔR and given by a set of six equations similar to those in the preceding example. The relationships represented by these equations when plotted give rise to graphs similar to those in Fig. 2 and from these when R_1 and ΔR are known P_c can be evaluated for any value of R.

Example 3

A distribution of sea clutter returns obtained experimentally on trials had been fitted with a Rayleigh distribution[9]. To improve on this a logistic curve was fitted using the plausibility and orthogonal polynomials. The fit of the logistic curve and the fit of the Rayleigh distribution to the observed data can be seen in Fig. 5.

Example 4

The phenomona of the previous examples, and the knowledge that first differences of a logistic form a curve resembling a normal curve, lead to a consideration of the properties of the normal curve relating to plausibility.

When ordinates of the cumulative standard normal curve are transformed into "plausibilities" and plotted, a curve is obtained (Fig. 6) which, for $0{\cdot}1 < P < 0{\cdot}9$, can be represented closely by a straight line. This means that over this range a symmetric logistic would give a good approximation. A closer, overall fit is given by a skew logistic over half the range or a cubic fitted over the whole range. The following approximations were obtained from symmetrical and skew logistics represented by the equations

$$P = \frac{1}{1+10^{-\cdot 724x}} \quad \text{and} \quad P = \frac{1}{1+10^{F(x)}}$$

where in the latter equation $F(x) = +0{\cdot}85743 + 0{\cdot}20663\ X_1 + 0{\cdot}006454\ X_2$; X_1 and X_2 being linear and quadratic expressions in X obtained from the use of orthogonal polynomials.

TABLE I. Approximations to P Using Logistic Curves.

$X = \left(\frac{x-\mu}{\text{s.d.}}\right)$	$P\left(\begin{matrix}\text{Symmetrical}\\ \text{Logistic}\end{matrix}\right)$	$P\left(\begin{matrix}\text{Skew}\\ \text{Logistic}\end{matrix}\right)$	P (Normal)
+ 0·25	0·604	0·602	0·600
+ 0·50	0·696	0·690	0·691
+ 0·75	0·777	0·771	0·773
+ 1·00	0·841	0·841	0·841
+ 1·25	0·890	0·895	0·894
+ 1·50	0·924	0·934	0·933
+ 1·75	0·948	0·960	0·960
+ 2·00	0·965	0·977	0·977

Where the agreement between a symmetrical logistic and the standard normal curve deteriorates corresponds to the tails of the normal distribution; it is often found that the normal distribution is a good fit to observed data except in the tails and it may be that in certain circumstances a better description of phenomena with small probabilities of occurrence is given by the logistic.

A transformation $Z = \frac{1}{2}\{\log P - \log (1-P)\}$, or $P = \dfrac{e^{2Z}}{1+e^{2Z}}$, was given by R. A. Fisher and F. Yates [10] together with other transformations useful in toxicological and similar applications which are open to treatment

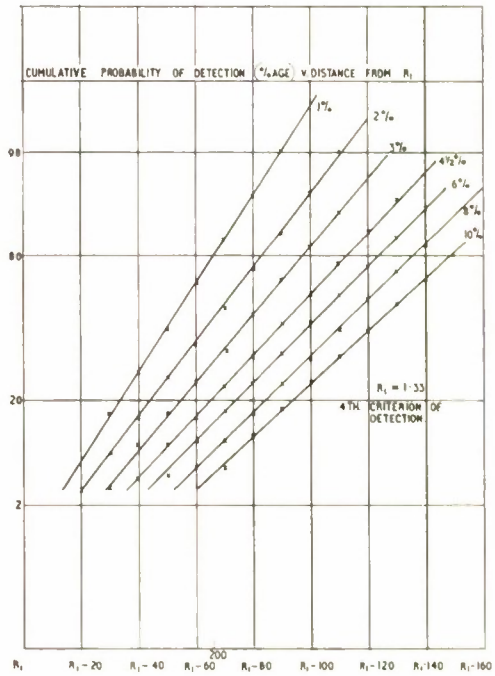

FIG. 4.

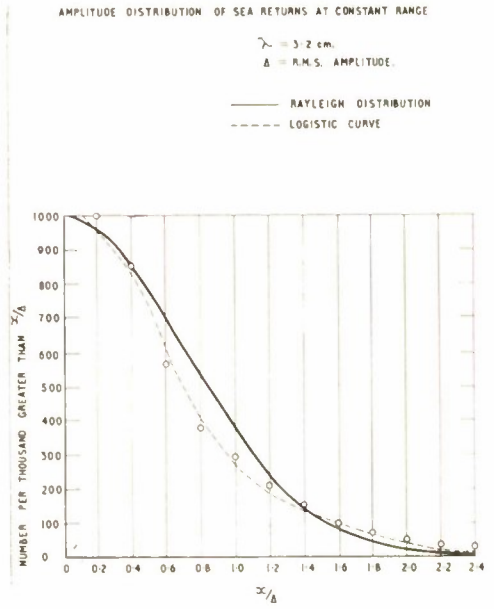

FIG. 5. Logistic curve fitted to sea clutter.

by the methods of probit analysis. This transformation is equivalent to replacing the normal curve by one in which the ordinate is $\frac{1}{2}$ Sech^{2}Z. A systematic account of the theory and practice of probit analysis, including useful references to the logistic curve, is given by Finney [11].

To recapitulate—in our experiences the advantages obtained from the use of asymptotic growth curves for approximations have not been limited to gains in computational ease. Their use has brought a philosophically satisfying simplicity to the subject and introduced certain basic theoretical measures such as plausibility, weights of evidence, *etc.*, which in fact lead to other applications; plausibility can be used in conjunction with orthogonal polynomials to provide an excellent curve-fitting technique, and a detection system for radar and sonar can be devised utilising plausibility and weights of evidence. Furthermore by the use of plausibility the cumulative standard normal curve over much of its range can be reduced effectively to a straight line relationship and over the remaining parts of the range the straight line will offer an alternative measure of small probabilities.

As well as simplicity they have introduced completeness; the number of situations considered by a computer programme was doubled and a relationship covered previously by two formulae is now covered by one—additionally asymptotic growth curves have been seen in the examples to have a wide range of application.

Finally they have added sensitivity in that overall growth patterns have been shown to have underlying structures involving parametric relationships and this has provided corresponding opportunities for analysis.

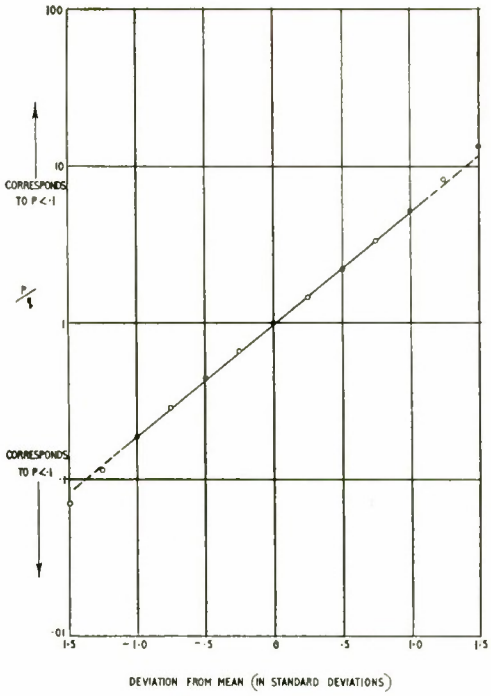

FIG. 6. The cumulative standard normal curve in terms of plausibility and departure from the mean.

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OIL POLLUTION FROM THE *TORREY CANYON*
Part 2
Laboratory Support At A.O.L.

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Introduction

With the grounding of the *Torrey Canyon* on the Seven Stones Reef the largest oil-spill at sea to date had occurred. The initial attack on the black menace pouring from the wreck was made by the Navy. It was natural therefore that procurement of detergents* for this work fell on Navy Department Contracts and all purchases to fight this pollution have been made by them. At first there were some fears that the operational demand for 70,000 gallons a day might be difficult to meet, but within a few days these fears were proved groundless, and the real difficulty was keeping the detergent salesmen out of the Maritime H.Q. Plymouth.

Over fifty British based and nearly two dozen Continental and American based detergent manufacturers were convinced that they each had the only answer to the Navy's need, and some were prepared to go to almost any length from approaches to the Prime Minister downwards to press their claims. With the production capacity of the order of ¾ million gallons/day in this country there were bound to be a lot of disappointed manufacturers.

To ensure as far as possible that the most efficient detergents were purchased manufacturers were asked to send samples of their products to A.O.L. for assessment. From Easter Monday and for the next 10 days samples arrived at an average of 10 a day. Within a day or so 90% of A.O.L's non-engineer scientific staff were tackling the growing heap of samples.

*NOTE.—In this context the term detergent refers to a mixture of an emulsifier or emulsifiers dissolved in an organic solvent.

Specification DGS/6992

A.O.L. had produced a bilge cleaning material specification DGS/6992 a year or so previously. The two main requirements were:—

(a) A cleaning test designed to ensure the material would clean the most difficult soiling found in H.M. Ships, *i.e.*, the hardened FFO on the fronts of boilers. The test surface was prepared by stoving a reference furnace fuel oil onto a metal plate. The soiled plate was then sprayed with detergent and after a soak time of 30 minutes washed with sea water.

(b) An emulsion test designed to ensure that the material would emulsify with sea water the most difficult to emulsify oil likely to be found in the bilges of H.M. Ships, so that the bilge water and oil could be discharged through the normal bilge pumps to the sea. The test consisted of emulsifying a Naval turbine lubricating oil OEP-69 containing 20% of detergent with sea water and then noting the breakdown of the emulsion over a period of five hours.

All submitted detergents were initially tested to this specification. Those assessed poor for either emulsification or cleaning properties were rejected at this stage. Additional tests were carried out on the better products in order to be able to advise Director of Contracts which were the "top-ten," from which purchases should be made.

Emulsion Stability of Detergents

Although the *Torrey Canyon* was carrying crude oil, a very different product from the highly refined and additive treated turbine oil OEP-69, the latter

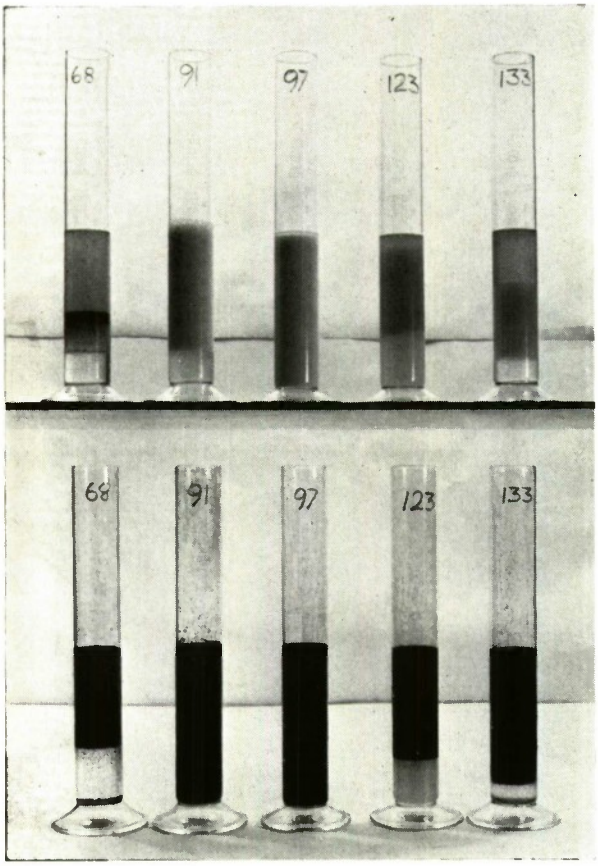

FIG. 1. Emulsion tests. OEP 69 (top), crude oil (bottom)

was considered to be a more difficult oil to emulsify and therefore would give better differentiation between the good and bad detergents. The best materials showed little emulsion breakdown after 24 hours, the poorest gave almost complete separation within one hour. Later when a supply of crude oil from the same source as the oil carried by the *Torrey Canyon* was obtained, the tests were repeated using crude oil with the better detergent materials. The results confirmed that in general, emulsions of crude oil and sea water were more stable than emulsions with OEP-69.

Fig. 1 shows a series of emulsion tests with OEP-69 (top) and crude oil (bottom) after approximately five hours standing. Sample 97 gave good emulsion stability, while 68 was assessed poor. The reduced separation into oil and water with crude oil emulsions can be seen.

Cleaning Test

While the cleaning test was not particularly relevant during the time the oil was still floating on the sea, the results did give some indication of the rate of penetration of the detergent into the oil film, and once the oil was driven ashore coating beaches, rocks and jetties, the cleaning properties became of prime importance. Results varied from complete removal to no removal of the fuel oil.

Results obtained in cleaning tests with some of the samples are shown in Fig. 2. Samples 5, 8, 36 and 63 were assessed good, while 30, 39 and 115 were poor.

Swirling Table Emulsion Test

As reports came in on the dispersal of the oil slicks at sea, it became apparent that emulsification of the detergent treated oil mainly occurred through wave action and to a lesser extent from the wash from the spraying vessels. The emulsion test in DGS/6992 designed to simulate passing the treated oil-sea water mixture through a centrifugal bilge pump, was hardly appropriate for this work and might even be giving misleading results, so a more realistic test was sought. Little published work was available on the assessment of these detergents. J. C. Taylor[1], in a lecture to the Institute of Petroleum gave a method used by Esso, but this did not simulate dispersal by wave action and was rather time consuming.

The U.S.A. have a specification[2] for a Solvent Emulsifier Oil Slick, but this requires large quantities of sea water and also a considerable number of man-hours per sample tested.

The Swirling Table emulsion test was therefore developed in a matter of days to better simulate conditions pertaining to oil dispersal at sea. Fig. 3 shows the table[3] in use, with four tests being run simultaneously.

The test consists of floating 2 ml of crude oil on the surface of 50 ml of 3% sodium chloride solution contained in a 100 ml squat beaker clamped to a swirling table. Three detergent treatment rates of 5%, 10%, and 20% of the volume of oil are used, the detergent being run carefully from a pipette onto the crude oil. The swirling speed of the table is adjusted so that the liquid in the beaker is swirled around with a wavelike motion without the surface actually breaking into turbulence. The degree of dispersion of the crude oil down into the salt solution is assessed each hour for up to five hours, into one of five classifications:—

(1) for complete emulsification of oil
(2) for some emulsification with oil slick (*i.e.* oil droplets on water surface)
(3) for some emulsification with a complete film of oil on water surface
(4) for some emulsification with a complete oil film, emulsion having dispersed no more into the top half of the sea water.
(5) for no emulsification.

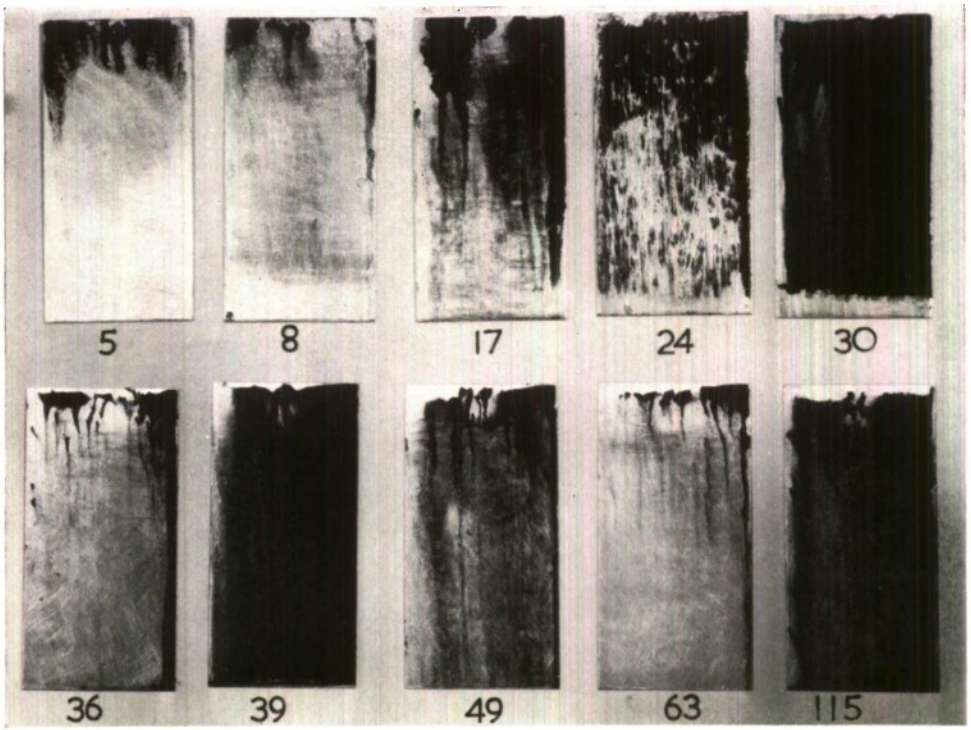

FIG. 2. Results of cleaning tests using various samples.

Table I gives results from some of the detergents tested. Sample No. 10 was one of the best products tested and was bought in large quantities. Samples No. 24 and 102 were two of the less efficient detergents.

Dispersal of "Chocolate Mousse"

Much, if not the majority, of the beach contamination was found to be a sea water in crude oil emulsion, and not plain crude oil as expected. The sea water content varied up to about 70%, at which level the contamination had the appearance and consistency of chocolate mousse. It is considered that the formation of this water in oil emulsion is due to surface active materials naturally present in the crude oil. No detergent is necessary for the formation of this emulsion, which could readily be prepared in the laboratory by the addition of sea water, a little at a time, to the well stirred crude oil. Because of the sea water content in the oil on the beaches, the efficiency of the detergents varied and a further merit assessment was requested to find the best products to deal with this "chocolate mousse".

The Swirling Table Test was modified to make this assessment. Into a dry 100 ml squat beaker was placed 2 gms of the "chocolate mousse" and the detergent was run onto it. After a soak time of 15 minutes, 50 ml of 3% sodium chloride solution was put into the beaker, and the table set in motion. Periodic assessments were made on the dispersion of the "chocolate mousse" into the salt solution.

TABLE I.

Sample Reference	*5*			*10*			*17*			*24*			*102*		
Treatment Rate %	*5*	*10*	*20*	*5*	*10*	*20*	*5*	*10*	*20*	*5*	*10*	*20*	*5*	*10*	*20*
Rating after 1 hr swirling	2	2	2	1	1	1	4	2	1	5	5	5	5	5	5
Rating after 2 hrs swirling	2	2	2	1	1	1	4	1	1	5	5	5	5	5	5
Rating after 3 hrs swirling	2	2	2	1	1	1	3	1	1	4	4	4	5	5	5
Rating after 4 hrs swirling	2	2	1	1	1	1	3	2	1	4	4	4	5	5	5
Rating after 5 hrs swirling	2	2	1	1	1	1	3	2	1	4	4	4	5	5	4

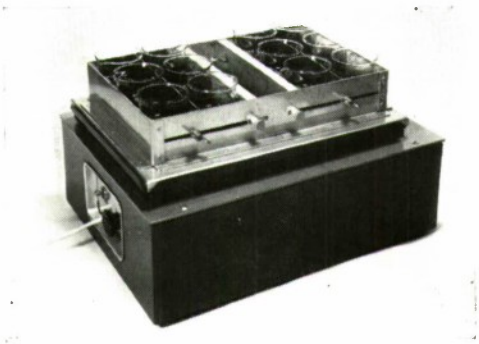

FIG. 3. The swirling table.

FIG. 4. Apparatus for the measurement of interfacial tension.

A different order of merit for the better detergent was obtained in this modified test, to that obtained with the standard method.

Leaching out of emulsifiers from detergent treated crude oil

The detergents used consisted of from 5 to 50% of an emulsifier or mixture of emulsifiers in an organic solvent. The solvent "carries" the emulsifier into the oil and then is fairly rapidly lost by volatilisation. Fears were expressed that if the emulsifier in the dispersed crude oil was rapidly leached out into the sea water, this would allow the dispersed droplets to reform oil slicks.

To test for leaching out of the emulsifier, the emulsified oil at the end of the five hour standard Swirling Table Test was poured into three litres of 3% sodium chloride solution, and stirred to completely mix the two liquids. After leaving for varying periods of time the emulsifier content of the salt water was determined. Initially measurement of the reduction in the surface tension was used to assess emulsifier content of the salt water, but this method gave obviously wrong results and a turbimetric method was substituted.[6]

Results indicate that the emulsifiers are leached-out by varying amounts from the treated crude oil into the salt solution. It is hoped to be able to link chemical constitution to the ease of leaching-out of the emulsifier.

Even though it appears certain that the emulsifier is leached-out of the detergent dispersed crude oil, over a period of time, it is not considered likely that there will be any reforming of oil slicks, when the dispersal takes place in the sea.

Interfacial Tension Measurements

A somewhat different approach used to assess the emulsification efficiency of the detergents was the measurement of interfacial tension between the detergent treated oil and sea water. For emulsification to occur readily, under the comparatively low energy provided by surface wave motion the interfacial tension should be reduced to zero.

Because of the rapid loss of the gaseous and petrol fractions from crude oil of the order of 25% in 24 hours, this work was carried out with Navy 75-50 fuel oil. Measurements of the interfacial tension between the oil containing 2% of detergent and sea water were made by the "drop-weight" method [4, 5].

The apparatus used is shown in Fig. 4. Air pressure applied to arm A forced the detergent treated oil as small droplets out through a hypodermic needle into synthetic sea water in arm C. Fig. 5 shows an enlargement of an oil drop forming in the sea water. Arm B was used for filling the apparatus. The volume of the drop at

the time of release is a measure of the interfacial tension provided the drop is formed slowly. The volume of oil measured on the calibrated scale of arm A on the release of 25 drops was noted, from which a mean drop volume was obtained. The interfacial tension γow is related to the volume of the drop Vo in the equation

$$\gamma ow = \frac{Vo\ (\rho w - \rho o)g}{2\pi a}$$

where 2a is the external diameter of the hypodermic needle $\rho w - \rho o$ is the difference in densities of the water and oil g the acceleration due to gravity.

For the 2% detergent oil mixture studied $\rho w - \rho o$ may be taken as constant. The interfacial tensions of the oil containing detergent and sea water $\gamma o^d w$ and pure oil and sea water γow can be expressed as a percentage in the equation.

$$\frac{\gamma o_d w}{\gamma ow} = \frac{Vo_d}{Vo} \cdot 100$$

The interfacial tension between the untreated oil and synthetic sea water was found to be 28·1 dyne. cm.$^{-1}$, and the values obtained for the oil containing 2% of some of the detergent is expressed as a percentage of this in Table 2.

TABLE 2.

Detergent No.	*% to Standard*
5	6·2
10	2·1
17	8·0
24	12·2
102	14·5

Although the order of merit from the results of the limited range of detergents given in Tables 1 and 2 are the same, this was not so for the complete range of detergents tested. The interfacial tension method also indicated that much smaller quantities of detergent would be sufficient to emulsify the oil, than were found to be required in practice. This is almost certainly due to the much more efficient mixing in the laboratory tests.

Because of the man-hours required for these determinations, one operator being fully occupied in doing a maximum of four tests in a day, this method was used mainly as an aid in determining cost/effectiveness of materials purchased by Director of Contracts.

Analytical Requirements

For the most efficient use, detergents should be sprayed into the spilt oil. During spraying some inhalation by the operator of detergent droplets is likely to occur. It was necessary therefore to check analytically the general nature of the detergent. Several submitted were found to contain chlorinated highly toxic solvents such as carbon tetrachloride and methylene chloride and such materials were banned.

The majority of samples were vacuum distilled to separate the solvents from the emulsifiers. The latter were initially characterized by infra red spectroscopy, and the solvents by boiling range, specific gravity, refractive index and element determination. Later when the apparatus was available the hydrocarbon solvents were analyzed chromatographically for aromatics, unsaturates and paraffins. Some use was also made of gas chromatography.

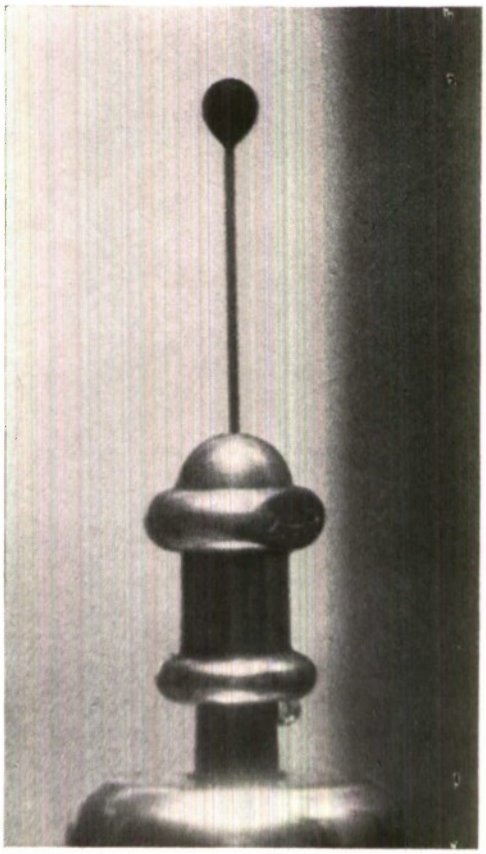

FIG. 5. Oil drop forming in seawater.

Analytical details of detergents were provided for the Naval medical service, Local Authorities and other government departments, but because

of the commercial confidence, the details cannot be published in this article.

Director of Contracts faced with bills approaching £1½ millions for detergents which were priced from under 10/- to nearly £1 a gallon, was concerned as to what was a fair price for each product. With emulsifiers costing in general four to five times as much as the solvents, with high aromatic solvents up to twice the price of low grade paraffinic solvents, and with the emulsifier content of the detergents varying from 5% to 50%, analytical details provided by A.O.L. undoubtedly helped to keep the final cost as low as possible.

Other Products for Eliminating Oil Spills

Some 18 other materials for sinking, coagulating, or absorbing spilt oil were received. These included vermiculite, prepared clays, natural sponges, fibreglass, chalk treated to make it lipophilic, and an organic material for pre-treating such absorbants as sawdust and straw to make them lipophilic.

These type of materials were not used by Britain, although the French used them at first exclusively, and only later for cleaning rocky areas of beach did they make use of detergents.

Although we did not use these materials for dealing with the *Torrey Canyon* spill, it seems likely that with any future spills use would be made of them. For this reason, A.O.L. is continuing with a limited amount of work on such products.

What of the Future?

As long as oil continues to be shipped across the seas, so periodically one must expect an oil spill to occur, and this could be greater than that associated with the *Torrey Canyon* as each year larger capacity tankers come off the slipways. Therefore procedures must be laid down for future accidents of this kind.

Two questions may help towards this end:—

(a) Was our treatment of the *Torrey Canyon* spill effective?

(b) Should it set the pattern for the future?

Considering that miles of beaches were contaminated by oil, on first thoughts one might answer No to question (a). This I suggest is a wrong conclusion. The oil that was treated dispersed, but because we did not have the spray equipment and probably not sufficient ships, we were unable to treat all of the very large quantities of oil which rapidly flowed from the ship before some reached the shore. Providing an oil spill occurs in a large enough sea area, it can be effectively dispersed by detergents.

A considerable volume of protests have come from marine biologists because of the use of detergents which in the undiluted state and when partly diluted with sea water kills seaweeds, shell fish and similar marine life. These protests are I feel, unnecessarily loud and a little shortsighted. Where detergents have been used to deal with smaller spills in the past, with similar results to marine life, such organisms have re-established themselves within a year or two. Secondly both those who rely for a living on the holiday makers, and the holiday makers themselves, would I'm sure, prefer a clean beach without seaweeds, crabs, limpets, *etc.*, than a beach swarming with marine life but smothered in oil.

The answer to (b) could be Yes if effectiveness was the only consideration and provided stocks of suitable spray equipment were held at strategic points around our coasts. Economically however the answer must be No. One hundred and seventeen thousand tons of crude oil was lost, and something approaching £2 million spent on losing it. In the writer's opinion the first requirement is booms suitable for containing an oil spill in the open sea; secondly equipment that could be fitted to any tanker to enable it to recover oil contained in such booms. Then for the part of the oil that would escape, a suitable sinking agent could be used in deep water, with detergent cleaning off any that arrived on the beaches.

Acknowledgements

Normal work at A.O.L. was almost completely stopped for a period of seven or eight weeks when dealing with the work resulting from the loss of the *Torrey Canyon*. Appreciation is expressed of the many A.O.L. staff who worked more than their required hours, including some shift work to keep apparatus running 24 hours a day. Mention must be made in particular of Mr. L. Butcher who developed the Swirling Table Test, Mr. A. Huxley who carried out the interfacial tension measurements, and Mr. C. Spilman who dealt with cleaning and emulsification tests and kept the samples moving through the test programme.

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WELDING OF STEEL IN COLD WEATHER

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ABSTRACT

The welding of steel in cold weather is considered under three headings: firstly, the effects of cold on men, materials and machinery; secondly, the metallurgical factors involved as revealed by experimentation and practical experience; thirdly, code requirements; fourthly, practical measures.

This paper is based on a more comprehensive report[1] prepared by the U.S. Welding Research Council, in which the published data is analyzed, together with the results of correspondence with experts in many countries.

Some conclusions may be drawn from the existing information about welding in cold weather, among the most important of which is that, provided proper precautions are taken, there is no absolute limit to the ambient temperature at which welding can be performed.

Finally, there are some implications concerning clothing, materials, equipment and methods for maintenance welding in support of Arctic warfare.

Effect of Cold on Men

Manual welding requires that the eyes and hands should work together. Exposure to cold does not affect visual reactions, but it does remarkably reduce the dexterity and strength of the hands. The exact conditions under which this begins have not been determined, but it was clearly present within half an hour at 15° to 20°F. Wind seems to play a part, but this has not been systematically investigated. In physiological terms, a decrease in touch sensitivity has been attributed to a reduction in the number of touch receptors functioning when the skin temperature is lowered. The impairment of manual dexterity becomes more apparent when operations are carried out without the help of visual observations. It seems most likely that in welding, impairment would usually take the form of difficulty with starting and maintaining the arc, rather than inaccuracy in locating the weld area.

It has been shown that the harmful effects of cold and wind can be reduced by wearing suitably designed heavy clothing. However, such clothing tends to interfere with the operator's ability to weld properly. This was the experience of a group working at Fort Churchill, Manitoba, during the winter of 1948-49[2]. Two highly skilled operators attempted to deposit welds with a controlled energy input at temperatures of −30°F, −20°F, −10°F and 0°F. They were shielded from the wind by a canvas enclosure, and wore Arctic clothing designed for the Canadian Armed Forces. Bulky felt inner mitts and heavy leather outer mitts destroyed their ability to make fine adjustments of arc length and electrode advance. Even when light woollen gloves were substituted and the work cycle was reduced to avoid excessive chilling, the extra clothing required for work at these low temperatures caused irregular deposition and resulted in a highly variable energy input. Resultant welds contained a much greater number of defects than did welds deposited by an automatic electrode feeder in a cold room[3].

It has been suggested that the problem of bulky clothing could be overcome either by using electrically heated suits similar to those used by aircrew, or by using lightweight suits heated by chemical canisters using breath moisture to generate heat.

This paper was presented at the C.D.S.O. meeting held in Canada, 1966.

At present the best that can be done is to protect the operator from the wind, provide warm clothing and regulate work shifts. One article, describing Russian experience with welding at −30°F, stated that warmly clothed operators worked for two hours, and rested for two hours in a warm shelter. However, conditions of temperature and exposure will vary with the nature of the work, and work periods should be fixed on the basis of experience.

No one likes the thought of working under unpleasant conditions. Men should be convinced that, with warm clothing provided, working in the cold is quite tolerable. It has been said that workers must be impressed with the idea "that the cold should not and will not be taken as an excuse for not getting the job done". This advice is contained in a booklet[4] for the guidance of men working on D.E.W. line construction. This was published by the Defence Research Northern Laboratory of the Defence Research Board, Department of National Defence, Canada, who have had considerable experience with men working in a cold climate. This booklet is recommended as providing much practical information for those who must work in the cold, with details on the importance of shelter, of keeping clothing dry, and of keeping warm.

Effect of Cold on Machines and Materials

Those who drive a car in Canada already know much about the effect of cold on machines. For the project at Fort Churchill, previously mentioned, a supposedly "winterized" engine-driven motor generator was supplied. This was found to be unsatisfactory after exposure to temperatures of around −34°F, and was abandoned in favour of a power source located in a heated room. Failure of an internal combustion engine to start and operate at low temperature can be caused by loss of battery efficiency, increased viscosity of lubricating oils and greases, changes in fit between bearings and shafts, and the reduced volatility of fuels.

The efficiency of a lead-acid battery is reduced at −40°F to a value of 10-25% depending upon the current drawn, compared with 100% at 80°F. Better efficiency, 40% at −40°F, is obtained with silver-cadmium batteries, but the latter cost approximately ten times as much as lead-acid batteries. It is customary therefore to use lead-acid batteries in cold climates and to maintain their efficiency with electrical heaters or by storing them in a warm place when not in use.

Special lubricating oils and greases are required for operation under cold conditions. This is because the wax present in ordinary lubricating oils precipitates at low temperature to form semi-solid wax sponges which prevent oil from reaching the pump. The viscosity index applied to oils for normal temperature is not valid in the case of these newer oils, which must be considered on the basis of actual viscosity at the temperature extremes of operation. Gear lubricants that are too viscous at low temperatures tend to "channel" rather than to flow around the gears to provide a lubricating film. Greases for low-temperature service must have low enough viscosity to be delivered to the lubrication site and they must be fluid enough that the starting torque is not excessive. Low-viscosity petroleum oils, or synthetics such as di-esters, silicones and uncon fluids, are used as bases in these low-temperature greases.

The volatility of gasoline must be high for winter starting, and in order to prevent difficulties associated with high volatility, such as vapour lock and carburettor-icing, these fuels must contain anti-icing compounds.

A change of fit or tolerance due to differential contraction may occasionally cause trouble. One investigator[3] reported difficulty with the steel shafts and bronze bearings in an automatic electrode feeder. At temperatures below −40°F, the bronze bearings would bind on the steel shaft of the variable speed carriage. When the bronze bearings were replaced by roller bearings properly lubricated for the low temperature, the machine operated satisfactorily.

Welding helmets provide a problem for operators wearing warm headgear because of the limited adjustment allowance on existing headbands. More urgent is the problem of frosting of the lens due to condensation from the operator's breath. This can be prevented by battery-powered resistance heaters, but the battery replacement cost is high. Hand shields have been successfully used since the operator can adjust the distance of the shield from the face to prevent frosting.

The most widely used insulation on welding cable is a synthetic type of rubber, 5BR, which serves as an insulation and a jacket. This synthetic rubber is flexible down to −45°F and will pass a cold bend test at this temperature. However, at lower temperatures, the cable insulation will become brittle and could fail after a sharp blow. It is conceivable that the operator would complain of the stiffness of the cable at −40°F, simply because it would resist flexing. Maximum flexibility at −40°F can be obtained by using either a butyl-type insulation or a special low-temperature geoprene. Butyl will sustain a flame, while geoprene will not. Neither butyl or geoprene is a standard item. Another possibility might be to use cable of slightly smaller size than that recommended for use at normal temperature. The heat generated should help to maintain flexibility in the insulation without being enough to cause damage.

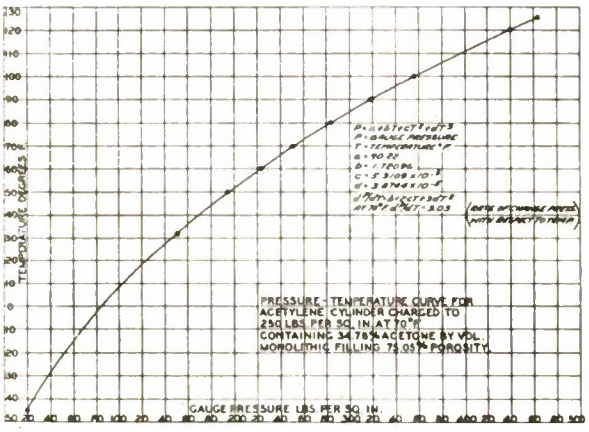

FIG. 1. Pressure-Temperature Curve for Acetylene Cylinder. This curve is based on an assumed set of conditions which are the average of those normally existing in a typical fully charged cylinder. Hence, they are almost certain never to be duplicated in any particular cylinder. Nevertheless, the importance of keeping acetylene cylinders protected from extremes of temperature; is readily apparent.

Acetylene may be needed for cutting and preheating. Carbide generators cannot, of course, be used below the freezing point of water, so that acetylene cylinders are generally used in cold weather. However, the pressure of acetylene dissolved in acetone in a cylinder is very sensitive to temperature changes as shown in Fig. 1. In this case, acetylene was charged to 250 psi at 70°F in a cylinder containing 34·8% acetone by volume. If the cylinder is stored at a temperature of 120°F, the gauge pressure will rise to 440 psi, and if the temperature drops to −45°F, the gauge pressure will register only 20 psi. Under field conditions at low ambient temperature, acetylene cylinders should be located in enclosures heated to approximately the temperature of charging.

The storage of electrodes under conditions of low temperature is not difficult. Since the moisture content of cold air is considerably lower than that of air at normal temperatures, storage at the working temperature will not harm ordinary electrodes. However, the danger of moisture precipitation when cold electrodes are brought into warm humid atmospheres must be considered. In the case of low-hydrogen electrodes, storage in sealed containers at work temperature or in a controlled-humidity cabinet would be necessary.

Published information concerning the over-all effect of low temperatures on men and materials is scanty. The foregoing deals with a few items of particular interest to those concerned with welding at low temperature.

Field Experience

A very great deal of welding on permanent or very large structures must be done out-of-doors, including bridges, structural steelwork for buildings, cranes, large spheres for nuclear reactors, storage tanks for petroleum and for the chemical industry, and pipelines. In many countries some of this work is inevitably done at low temperatures.

(a) *No Special Precautions*

On several occasions, work has been carried out at quite low temperatures without any serious difficulties being reported.

The Bureau of Ships has reported that in ship construction for the U.S. Navy, carbon steels have often been welded at ambient temperatures well below 32°F. The factor which decided whether welding should be continued or not was the endurance or comfort limit of the welder. Prior to the attack on Pearl Harbour, shipyard welding would stop if the ambient temperature fell to about 10°F. In Canadian shipyards, welding of shell plating and internal structural members has been carried out at ambient temperatures down to 0°F.

An account has been given of the successful construction in the United States during the winter of 1936-37, of two syphon lines to pipe water across the Continental Divide and supply the city of Denver. Near West Portal, Colorado, the ambient temperature was in the range −35°F to −52°F during the day. The pipe joints were made in material conforming to *ASTM-A*70-33, and the welding procedures were in accordance with paragraph *U*-69 of the Unfired Pressure Vessels Section of the *A.S.M.E.* Boiler Code. This entails no restrictions or special precautions with regard to welding at low ambient temperatures.

It seems likely that in many parts of the United States and Canada, pipelines have been welded without special precautions at low ambient temperature. Fig. 2 shows winter construction in progress on a small-diameter line.

In Canada, and in the colder parts of the United States, the introduction of double-jointing techniques has made it possible for pipeline companies to continue some aspects of the work during the winter months (see Fig. 3). The method has been used, for example, in trunk lines made from 5*LX*-52 steel in Manitoba and Alberta, with temperatures regularly around −30°F and occasionally as low as −48°F. Double-jointing consists of joining the normal 40 ft. lengths to make 80 ft. lengths. By this means 50% of the girth welding can be carried on, when temperatures are low, under conditions rather better than are obtainable in the field. Semi-automatic submerged arc welding is used with a joint geometry approaching a close-

FIG. 2. Winter construction of pipeline.

butted preparation, necessitating partial removal of the factory-made bevel on the pipe ends. Large propane burners are used to remove ice and snow from the pipe ends, the heating period required being in the order of half a minute. Since its introduction, the method has been improved by increased use of automatic methods, the elimination of tack welding, higher speeds, and increased efficiency. In addition, the double-jointing yard has become fully mobile. There seems little doubt that the high heat input characteristic of the method is the main factor responsible for its success. Trans-Canada Pipe Lines Ltd. have reported that a number of double-jointed section welds have been cut and tested. It was concluded that the process produces sound welds.

In the U.S.S.R., unlike the practice in other countries, the rules of the Shipping Register apparently permit welding construction and repair of ship hulls in ordinary low-carbon steels without regard to the air temperature. Similarly, some welding in steel construction for industrial and civil purposes can be done with low-carbon steels at fairly low temperatures without special precautions.

FIG. 3.

Though full details are not always available, investigations into the brittle failure of large storage tanks (165,000-350,000 cu. ft. capacity) in the U.S.S.R. suggest that low-temperature welding difficulties may have played a part. In one particular case, with ambient temperatures between −50°F and −70°F, intersecting cracks in the form of a cross were produced as the arc was struck; these were usually 8 to 12 in. long and sometimes more.

There may be many instances where welding has been carried out without preheating at low ambient temperatures in Canada and the United States. However, the evidence is difficult to find, perhaps because, in most cases, such practices would involve a technical breach of the relevant codes.

(b) *With Special Precautions*

In many cases, welding construction has been carried out at low temperatures, using special electrodes or augmented heat input. This has been done either to comply with code requirements or because it was thought advisable to help overcome the metallurgical problems arising. These methods are discussed later.

Experimental Work

(a) *Methods of Approach*

Experimental work on welding at low temperatures has been done under a variety of conditions. Welding under controlled conditions in a cold room appears to be best. Work in the open air at low atmospheric temperatures offers poor control. Pre-cooling the plates or welding assembly has the disadvantage that condensation or frosting can occur on the plate surfaces. The aims of the experimenters have often been quite different, some being interested in cracking problems, others in joint properties, particularly in relation to brittleness, and some more generally wih any problems relating to welding at low temperatures.

(b) *Heat-Affected Zone Cracking (Manual Metal-Arc Welding)*

Heat-affected zone cracking usually occurs in the coarse-grained part of the brittle hardened martensitic zone which forms adjacent to the weld in hardenable steels. Sometimes the cracks are so small that they can only be seen on polished sections with the aid of a microscope, but often are opened up by welding stresses so that they can be easily seen by eye. When seen visually, they appear

to run very close to the junction between the weld and the base metal.

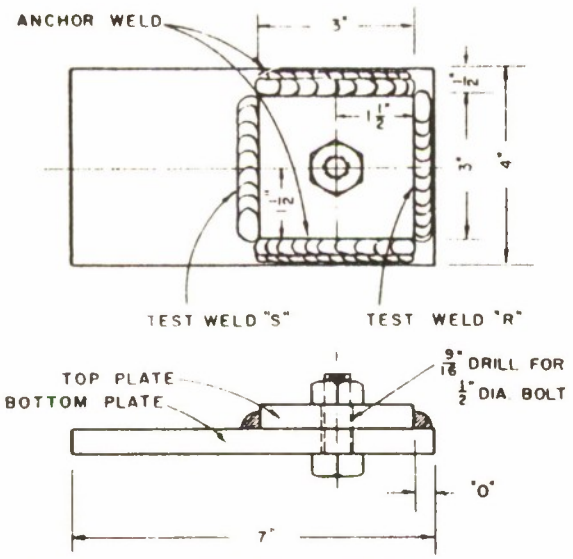

FIG. 4. Controlled thermal severity testpiece.

One of the weldability tests designed to test susceptibility to heat-affected zone cracking is the Controlled-Thermal-Severity, or C.T.S. test (see Fig. 4). Two test plates are connected with a bolt and two anchor welds. Two test fillet welds are laid down under prescribed conditions and later examined for cracks. Several assemblies may be made up using different plate thicknesses. Cottrell[5] showed that for any given plate/temperature combination, cracking will occur if the cooling rate at 300°C exceeds a certain value. In one case[6], tests showed 5% cracking with the test plates at 20°C (68°F), and 72% cracking with the plate temperature at −50°C (−58°F). Cracking was initiated at approximately the same critical cooling rate, illustrating that the principal effect of welding at low temperatures is to increase the cooling rate. In Belgium, this kind of relationship is relied upon to such an extent that the weldability of a particular steel is sometimes gauged in terms of the lowest temperature at which the steel can be welded without sustaining heat-affected zone cracking.

A long-term project[7] on the effects of welding is in progress in the Physical Metallurgy Division of the Department of Energy, Mines and Resources in Ottawa. The principal method of investigation is to undertake standard weldability tests, such as the C.T.S. test, in a cold room with ambient temperatures in the range 70°F to −60°F. Work so far confirms that there is an increased tendency to crack as the temperature is reduced. A similar general trend has been noticed by other investigators in various countries using the cruciform test, bead-on-plate tests, restrained butt-weld tests, H-plate tests, simulated joints, as well as the C.T.S. test.

In tests at the Battelle Memorial Institute, simulated joints on pipeline sections using 5*LX*52 steel showed that the percentage of cracked sections through root-pass welds increased from 0% at 70°F, to 19% at 55°F, to 34% (average) at 40°F, and to 37% (average) at 20°F. In complete welds, the extent of cracking could be reduced by minimizing the delay between the first and second welds, and by completing the whole joint in a two-hour period. Preheat at 200°F, or alternatively the use of low-hydrogen *E*7016 electrodes, was effective in preventing cracking.

(c) *Weld-Metal Cracking (Manual Metal-Arc Welding)*

The production of fissures (minute cracks) in as-deposited weld metal has been a subject of interest to many since the discovery of the phenomenon by Flanigan[8] in 1947. It was known from the first that their formation was encouraged by high cooling rates. Since then, several authors have shown that the number of fissures increases with lower deposition temperatures.

The Lehigh test (see Fig. 5) is used to indicate the susceptibility to weld-metal cracking. The test is being used in the long-term project, in the

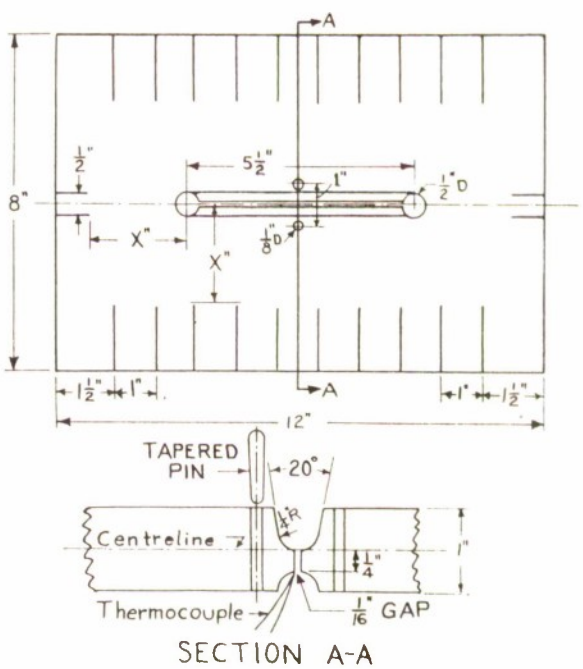

FIG. 5. The Lehigh testpiece.

FIG. 6. Automatic welding equipment inside cold room, used by Agnew[3]

Physical Metallurgy Division of the Department of Energy, Mines and Resources mentioned previously. In this test, the weld is laid down in a groove, leaving an open root. Transverse and longitudinal stresses develop on cooling leading to biaxial restraint. The test severity can be varied by cutting slots in the plate, allowing the latter to deflect as a beam. It has been suggested that the major weld cracks produced in the test are formed by linking up the larger fissures in the weld metal.

Agnew[3] used the Lehigh test to examine the influence of ambient temperature in the range 70°F to −80°F on the tendency for weld-metal cracking. The equipment used in this program is illustrated in Figs. 6 and 7. Agnew confirmed that the number of fissures increases with lower deposition temperatures, but it appeared that there was a greater effect between 70°F and 0°F than between 0°F and −80°F. This author obtained good results (most welds uncracked) on some low-hydrogen electrodes tested at −80°F with the Lehigh test at full restraint. There was a strong indication that, at lesser restraint or at slightly higher temperatures, no trouble would be encountered. Crack-free welds were also obtained at −80°F with inert-gas metal-arc deposits, using consumable electrodes.

(d) *Properties of Arc-Welded Joints*

Many authors have reported on the effect of low ambient temperatures on the mechanical properties of arc-welded joints. In general, tensile strength and yield strength are not much affected and, if anything, are increased somewhat. Ductility and impact strength, however, were sometimes adversely affected. The Tee-bend test has been used to evaluate the performance of welded joints; in one case it was concluded that low deposition temperature had a markedly deleterious effect on steels containing more than 0·20% carbon. Impact and bend tests carried out by *Commission II* of the *International Institute of Welding* showed that greater deterioration occurred in the range 68°F to 32°F than in the range 32°F to −4°F.

FIG. 7. Controls and recording equipment outside cold room, as used by Agnew[3]

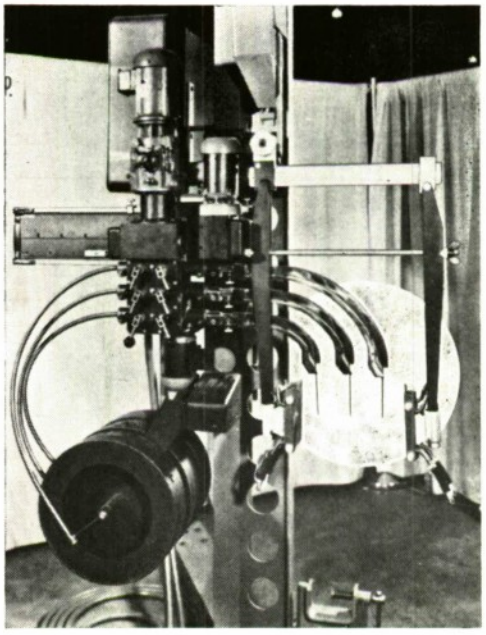

FIG. 8. Electro-slag welding equipment.

(e) *Submerged Arc Welding and Electro-Slag Welding*

These two processes are high heat processes and therefore worth considering for welding at low temperatures. Both processes, but especially electro-slag welding, are used widely in the U.S.S.R. Typical equipment used for electro-slag welding is shown in Fig. 8. Russian investigations showed that submerged arc welds laid at low temperatures (−58°F) were lower in ductility by about 5% and showed somewhat reduced notch-toughness compared with welds laid at ordinary temperatures (59°F). Employing welding procedures devised by the Research Institute, more than 25,000 joints have been made in long-distance pipelines in Siberia and the northern territories of the European U.S.S.R.

Electro-slag welding tests were done in the U.S.S.R. at an air temperature of 64°F, but with the plates chilled to −40°F before welding. The low deposition temperatures did not have any adverse effect on tensile strength or ductility, but the impact values fell off somewhat.

(f) *Effect of Wind Velocity*

The adverse effects of wind during field welding are widely recognized, and it is clear that wind will aggravate the difficulties of welding at low temperature. However, few people have investigated directly the effect of wind and low temperature in combination.

In one investigation it was found that effective welding could not be carried on with a wind velocity in excess of 20 m.p.h., and the arc could not be maintained at all with wind velocity in excess of 30 m.p.h. Although there was little effect on weld strength, ductility tends to decline with increasing wind velocity, and the effect is more marked at the lower welding temperature. The weld metal also showed poorer impact values in tests with wind velocity of 20 m.p.h.

Wind shields and shelters, of various materials and of differing shape and complexity, are commonly used for all kinds of outdoor welding. These can vary from simply constructed boxes (Fig. 9) to quite large complex structures (Fig. 10).

Code Requirements

Some mention of requirements for welding in cold weather is made in the following U.S. and Canadian Standards:

(a) Welded Highway and Railway Bridges—*A.W.S. D*2. 0-56.
(b) Welding in Building Construction—*A.W.S. D*1. 0-63.
(c) Field Welding of Storage Tanks—*A.W.S. D*5. 1-55.

FIG. 9. Shelters for welding operations.

(d) Steel Tanks, Standpipes, Reservoirs, and Elevated Tanks, for Water Storage—*A.W.S. D*5. 2-59, *A.W.W.A.* D100-59.
(e) Welded Oil Storage Tanks—*A.P.I.* 12*C*-1958.
(f) Design and Construction of Large, Welded, Low-Pressure Storage Tanks—*A.P.I.* 620 (1956).
(g) A.S.M.E. Boiler and Pressure Vessel Code, Section VIII Unfired Pressure Vessels (1959).
(h) Welding of Bridges, Buildings and Machinery — *C.S.A. W*59 (1946 — revised 1950).

All of these standards specify or at least recommend that no welding shall be done if the welders are exposed to inclement conditions. The Canadian

FIG. 10. A complex shelter for outdoor welding.

Standards Association Specification *W59* requires that at temperatures below 40°F, the welder and the work must be adequately protected against the direct effect of wind and snow, and all necessary steps are to be taken to enable the operator to work in reasonable comfort. This seems a logical approach. The shelters may be heated if necessary so that the "local" ambient temperature is high enough to permit the welder to make good quality welds. This was done in the case of the shelter illustrated in Fig. 9.

All of these standards prohibit or tend to prohibit welding when the primary steel temperature is below 0°F. The term "primary steel temperature" means the temperature of the steel resulting from exposure to the ambient conditions, as distinct from the temperature of the steel in a joint area resulting from local preheat and interpass control prior to and during welding. In addition, some of the standards specify that the base plate temperature shall be raised (by preheat) to a certain minimum value in the range 50°-200°F if the plate thickness is above a certain minimum in the range 1 to 2 in.

Most of the standards require that the starting point of welding is to be heated to a temperature "warm to the hand", when the primary steel temperature is in the range 0 to 32°F. This requirement is presumably based on the idea that the starting point of the weld is more susceptible to weld difficulties or defects when the steel is at a temperature below about 32°F. Apparently it is expected that, once welding is in progress, the heat flow in front of the advancing weld will act in the same way as the local pre-heat at the start of the weld. This is not correct. Care should always be taken in pre-heating to heat a sufficiently large mass of metal along the path of the intended weld to prevent a premature drop in temperature, from that prescribed, before welding is completed.

The standards require greater precautions as the plate thickness is increased. This is related, not only to the greater heat draw-off from a weld deposit, but also to the tendency for slightly higher carbon and/or manganese level in the thicker steel. Presumably, the more rigid requirements for shapes and bars are dictated by the likelihood that these will have greater hardenability than will plates.

Rather precise directions are given in British Standard Specification, *B.S.* 2642-1965, for General Requirements for the Metal-Arc Welding of Medium Tensile Weldable Structural Steel to *B.S.* 968 Type 2. This particular steel contains maximum percentages of 0·23 carbon, 1·8 manganese, 0·5 nickel, 0·35 chromium and 0·6 copper. For butt welds, graphs are provided which show the maximum run lengths to be made with an 18 in. long electrode (this is a convenient way of controlling the minimum weld size), for different combinations of total plate thickness, electrode size and plate temperature. Other graphs similarly make it possible to determine the minimum size of single-run fillet welds. The system of control incorporated in this Standard has been adapted[9] for a new Canadian steel, *C.S.A. G*40.12, which somewhat resembles the U.K. steel *B.S.* 968 Type 2.

The requirements in a U.S.S.R. standard "Technical Regulations for the Fabrication and Assembly of Structures from Carbon and Low-Alloy Steels", vary depending upon air temperature, plate thickness, type of steel and type of structure. For example, at all temperatures above −22°F, low-carbon steels used in "structural steelwork (lattice) construction" may be welded without preheat in thicknesses as large at 1·18 in., but in "three-dimensional sheet constructions", the limit is reduced to 0·63 in.

Practical Measures

(a) *Use of Low-Hydrogen Electrodes*

Low-hydrogen electrodes are generally less apt than other electrodes to produce heat-affected zone cracking, and weld-metal fissuring. Their obvious advantages for low-temperature welding are widely recognized, and have been demonstrated by numerous investigators. Precautions must be taken to keep these electrodes dry, as they tend to pick up moisture when exposed in a humid atmosphere.

(b) *Thermal Control*

Some welding processes are inherently less susceptible to the effect of low ambient temperatures, for the reason that the rate of energy input is high. These include submerged-arc welding, thermit welding, electro-slag welding, enclosed welding, *etc.*

An obvious means of preventing the high cooling rates normally associated with the effect of welding at low temperatures is to increase the heat input. For some applications, rough qualitative rules have been drawn up for this method of control. Following work done at the Battelle Memorial Institute, it is now customary in pipeline welding to start the second pass within five minutes of completing the first pass in order to prevent cracking. Somewhat similar is a U.S.S.R. recommendation for the welding of pipelines and reservoirs that multi-pass welding should be employed extensively in winter, so that before cooling down completely, most welds are re-heated by succeeding passes. In manual welding, no pass longer than 3 ft. should be deposited before applying a covering pass. A comparable distance for automatic welding would be about 20 ft.

Canadian workers[2] have suggested that long welds should be made in blocks, so that the inter-

pass temperature is maintained as a satisfactory level. From the same source comes the suggestion that in some cases welds could be laid on the plate surface just outside the welding groove for preheating purposes if auxiliary heating services are not available.

A rough rule used in the U.S.S.R. is that the specific heat input should be increased by 4% to 5% for each 18°F drop in temperature below normal shop temperatures (apparently in the range 50° to 68°F in the U.S.S.R.). It was suggested that the increase should be made primarily by increasing the arc voltage. However, the reason for this is not known, and it would seem easier normally to make such adjustments by means of the welding current. Other calculations[1] indicate that the heat input should be increased by 7-8% for every 18°F drop in temperature in order to maintain normal cooling rates.

A system of weldability control proposed by Cottrell[5] was based upon the use of the *C.T.S.* test. A weldability index letter from *A* to *G* was assigned to any particular steel after carrying out a prescribed schedule of testing. Bradstreet[10] later suggested that the weldability index for the steel could be calculated using a formula devised by Winterton[11].

$$\text{C.E.}=\text{C}+\frac{\text{Mn}\%}{6}+\frac{\text{Ni}\%}{20}+\frac{\text{Cr}\%}{10}-\frac{\text{Mo}\%}{50}-\frac{\text{V}\%}{10}+\frac{\text{Cu}\%}{40}$$

The carbon-equivalent (C.E.) of the steel may be converted into a weldability index using a table provided by Bradstreet. In either case, whether the weldability index is determined by test or by calculation, the value can afterwards be substituted in a table to find the minimum plate temperature required for any particular joint, taking into account the electrode diameter and the joint severity (total plate thickness available for heat flow in $\frac{1}{4}$ in. units). This data shows for example that steel with a weldability index of B can be welded in thicknesses up to $\frac{1}{2}$ in. with electrodes of 6S.W.G. or larger (more than 0·192 in. diameter) at temperatures down to −58°F.

Practical Implications

The foregoing analysis of the present situation in welding in cold weather has some practical implications for planning maintenance welding in support of Arctic warfare, or indeed for anyone planning substantial welding work under low-temperature conditions.

Clothing, including welders' helmets and gloves, welding equipment including power sources, cables and auxiliaries could all be selected from what is presently available on the basis of previous experience. Better still, further development work could be done in this area and specifications could be drawn up to cover items that are truly serviceable in cold weather.

Steels for low-temperature service should be chosen to exclude or minimize the possibility of brittle failure. However, if welding construction or extensive repair by welding is to be done under low-temperature conditions then weldability is another factor which should be given consideration in steel selection.

Serious consideration should be given to the use of high-energy processes for extensive construction. These include submerged-arc welding, electro-slag and electro-gas welding, thermit welding, enclosed welding, *etc.* However, it should be noted that such processes are usually not adaptable for repair welding.

Low-hydrogen electrodes are preferred for manual arc welding because they minimize those welding defects which result from rapid cooling conditions such as heat-affected zone cracking, weld-metal fissuring, *etc.*

For a particular job, limited perhaps to one or two steels, working in a certain range of plate thickness, it should not be too difficult to work out proper procedures with appropriate thermal control for welding, suitable for the lowest service temperatures expected, though it might be necessary to supplement any theoretical studies with a test program. Under these conditions, it should be possible to continue welding work no matter how low the temperature falls. The experimental work that has been done certainly shows that the problems increase as the temperature declines, but there are no sudden changes, and therefore no support for the somewhat arbitrary cut-off temperatures which are to be found in many specifications.

References

(1) Winterton, K., Campbell, W. P., and Nolan, M. J., "Welding of Steel at Low Ambient Temperatures", *Bulletin No. 86, Welding Research Council* (March 1963).

(2) Nicholls, H. J., "Low Temperature Welding at Churchill, Manitoba, winter 1948-49", Investigation No. 2537, Bureau of Mines, Ottawa, Canada, May 1949.

(3) Agnew, S. A., "Root Bead Welding of Structural Steel Restraint Specimens at Low Ambient Temperatures", Mines Branch *Research Report No. P.M. 222* (Sept. 1957) Department of Mines and Technical Surveys, Ottawa, Canada.

(4) Coffey, M. F., "Aids to Working in the Cold", *DRNL Tech. Note* 38/55, Defence Research Board, Canada, November 1955.

(5) Cottrell, C. L. M., "Controlled Thermal Severity Cracking Test Simulates Practical Welded Joints", *Welding Journal*, **32**, 6 (June 1953) 257s-272s.

(6) Cottrell, C. L. M., and Bradstreet, B. J., "A Method for Calculating the Effect of Preheat on Weldability", *British Welding Journal*, **2**, 7, 305-309. Also: "Cal-

culated Preheat Temperatures to Prevent Hard-Zone *Cracking in Low-Alloy Steels", British Welding Journal,* **2,** 7 (July 1955) 310-312.

(7) Girard, L. G., "Weldability of Steels at Low Ambient Temperatures", Physical Metallurgy Division *Internal Report PM-R*-63-41 (November 1963) Department of Mines and Technical Surveys, Ottawa, Canada.

(8) Flanigan, A. E., "An Investigation of the Influence of Hydrogen on the Ductility of Arc Welds in Mild Steel", *Welding Journal,* **26,** (4) (April 1947) 193s-214s.

(9) Campbell, W. P. and Winterton, K., "Tentative Recommendations for the Avoidance of Underbead Cracking when Welding Steel Conforming to C.S.A. Standard G40.12-General Purpose Structural Steel", Physical Metallurgy Division *Internal Report PM-M*-64-10 (September 1964), Department of Mines and Technical Surveys, Ottawa, Canada.

(10) Bradstreet, B. J., "Methods to Establish Procedures for Welding Low Alloy Steels", *Engineering Journal* (November 1963) 37-41.

(11) Winterton, K., "Weldability Prediction from Steel Composition to Avoid Heat-Affected Zone Cracking", *Welding Journal,* **40,** 6 (June 1961) 253s-258s.

Notes and News

Admiralty Materials Laboratory

Mr. B. W. Lythall, C.S. (R.N.), paid a visit to A.M.L. on 2nd August, 1967, and toured some of the laboratories. The visit ended with a valuable discussion with senior members of the staff on the "Report of the Working Party on Materials Research" and on the exploitation of fall-out to civil technology.

Mr. J. F. G. Condé, S.P.S.O., joined on 1st September, 1967 to take up his appointment as Head of the Metallurgy Division. Mr. Condé had served four years at the former Admiralty Gunnery Establishment, leaving Portland in 1958 to join the U.K.A.E.A. Since 1960, he has worked with the O.E.C.D. *Dragon* Project Team at Winfrith.

Dr. K. J. Cathro, Senior Research Scientist of the Commonwealth Scientific and Industrial Research Organisation, Australia, joined the Chemical Engineering Division on 6th June, 1967, to work with the Fuel Cell Group for a period of six months.

Miss P. D. Haslar, Scientific Assistant, retired on the 18th July, 1967, on her 65th birthday after 43¼ years' service, first with the R.N. Cordite Factory and subsequently with the A.M.L. library. In addition to her normal duties, Miss Haslar made a significant contribution to the social requirements of the Establishment, taking an active part in all productions of the "Holton Heath Players" and running the staff magazine club. To mark the occasion her colleagues presented her with a photographic slide projector, and members of the "Holton Heath Players" with a cut glass vase.

The Laboratory participated in the 1967 Portsmouth Navy Days by contributing exhibits to stands presented by H.M.S. *Sultan* and H.M.S. *Collingwood.* Exhibits included a demonstration of the properties of "Hidamet" alloys, a display of a new low-cost eddy current crack detector developed at A.M.L. and a static display of fuel cells. A working 10½ft. dinghy propelled by fuel cell was also on display and received considerable local publicity. In addition, a demonstration was provided of the sensitivity and inherent simplicity of modern techniques for measuring displacement, in the form of a "try your strength" machine which also proved popular with visitors.

A paper entitled "Inorganic Non-Metallic Bearings with Special Reference to the Use of a Silicon Nitride" by D. J. Godfrey and P. G. Taylor, was presented at the Special Ceramics Symposium of the British Ceramic Research Association at Stoke-on-Trent in July 1967.

The following papers have been published:—

"The Cirriped Fauna of Tropical West Africa" by H. G. Stubbings, *Bull. Brit. Mus. Nat. Hist. (Zool.),* **15** (1967) 227.

"Fluorescence of Charge Transfer Complexes" by G. D. Short and C. A. Parker. *Spectrochim. Acta,* **23** (1967) 2487. "Stainless Steel and the *Gipsy Moth IV* by D. Birchon, *Anti-Corrosion,* **14** (1967) 8.

The latter paper records the conclusions of an examination of the stainless steel fittings in *Gipsy Moth IV* which Mr. Birchon was invited to make following Sir Francis Chichester's return to Plymouth.

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Admiralty Surface Weapons Establishment

Excellent voice communication was established between A.S.W.E. and S.R.D.E. on 9th September using the American LES5 Communication Satellite. LES5 is an experimental UHF Communication Satellite which was launched in May of this year into a sub-synchronous orbit. It is designed for tactical communication between mobile terminals fitted with relatively simple equipment.

Mr. A. Woroncow and Dr. J. Croney have been awarded the Clerk Maxwell Premium for their paper "A True I.F. Logarithmic Amplifier using Twin-Gain Stages". This was judged by the Council of the Institution of Electronic and Radio Engineers to be the most outstanding paper published in the *Journal* during 1966. Dr. Croney also receives the Brabazon Award of the Institution for his paper "Improved Radar Visibility of Small Targets in Sea Clutter" which was judged the most outstanding paper in the field of Radar and Navigational Aids. Congratulations are also due to Dr. Croney in view of his promotion to D.C.S.O. on individual merit for his personal contributions to radar science in the fields of Target Detection in Sea Clutter and Inertialess-scanning Antennas.

His colleagues will be pleased to learn that Dr. H. A. French, the Deputy-Head of the Electronic Warfare Division, has been promoted to the rank of S.P.S.O. on individual merit for his research into advanced signal-processing systems and computer-aided pattern recognition which is internationally recognised as placing him in the forefront of his own particular field.

Mr. W. R. Carter visited Milan on 11th September to attend the AGARD Symposium on Advanced Navigational Techniques. It is hoped that a summary of the proceedings will appear in a future issue of the *Journal.*

Mr. Bernard Small of the Microwave and Components Group of the Naval Electronics Laboratory Center, San Diego, California, has arrived at Funtington for a year's tour of duty with the Antenna Techniques Division under

the exchange arrangement between A.S.W.E. and N.E.L.C.

Mr. Brian Gladman is leaving Funtington in November for a two-year spell in the Antenna Group of N.E.L.C. as the conjugate link of the exehange.

The Imperial Service Medal was presented to Mr. M. J. Lynch on Friday, 18th August by Mr. Stewart Watson, the Director of A.S.W.E. Mr. Lynch, having been originally apprenticed in 1917, retired as a Laboratory Mechanic on 31st March.

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Central Dockyard Laboratory

An article entitled "Antifouling Paints and Processes" by Dr. C. D. Lawrence was published in *The Engineer* dated 2nd June, 1967, and it is also intended to include it in our January, 1968 issue.

"The Use of Pulsed Applied Voltage in the Derivation of Corrosion Rates from Polarisation Resistance Measurements" by Mr. J. C. Rowlands and Mr. M. N. Bentley was published in *British Corrosion Journal*, **2** (May 1967).

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R.N. College, Greenwich awards M.Sc.

The Counеil for National Academie Awards has reeognised for the award of the degree of M.Sc., the Nuclear Advanced Course of the Royal Naval College, Greenwich. The Course, which lasts one ealendar year, and eommences in September of each year, has been run hy the Departmcnt of Nuclear Science and Technology (Professor J. Edwards) for eight years and is the first course at the College to be so reeognised. With the steady expansion of the Department in experimental and digital and analogue computing facilities, it now offers an impressive and advance eourse of leetures, projects and reaetor system design studies. The course is based on the small mobile pressurized water reaetor system of interest to the Navy, and numbers amongst its students, Naval Officers, members of the Royal Naval Seientifie Service and the Royal Naval Engineering Serviee, representatives from Rolls Royce and Assoeiates, and other industrial firms associated with the Navy's nuclear propulsion programme.

The following students from Nuclear Advaneed Course No. 8 have been recommended for the award of the Council's degree of M.Sc.: Mr. D. L. Ryall, R.N.S.S., Mr. J. M. Barton, R.N.S.S., Cdr. V. L. Snarey, R.N.; Inst. Lt. Cdr. H. Wilkie, R.N., Lt. A. D. Ferguson, R.N.; and Lt. T. R. Worth, R.N.

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Services Electronics Research Laboratory

On September 18th Mr. J. D. L. H. Wood presented a paper "Performance of Targets in sealed-off neutron tubes" at the third Euratom Symposium on "Aceelerator targets designed for the production of neutrons" held in Liege. He also visited the Geldorp research laboratory of Philips Ltd. near Eindhoven to see their work on neutron tubes and eyclotrons.

Mr. L. Large visited Chalk River, Canada 17th-21st September to attend a conferenee on "Atomie collisions and penetration studies with energetic (keV) ion beams", whilst in the same month Dr. S. Bass attended the International Conference on II/IV Semieonduetion Compounds at Brown University, Providence Rhode Island, and visited some researeh laboratories working in this field.

Mr. J. E. Bounden left on the 1st September to join the Applied Physics and Technieal Services Division at R.R.E. and Dr. J. Carroll has been appointed to a lectureship in the Eleetrieal Engineering Department at Cambridge, and elected into a Fellowship at Queen's College. Dr. Carroll left S.E.R.L. Harlow at the end of September.

Dr. Rita Seel, who joined S.E.R.L. from Cambridge for six months to work in the laser group, has moved to a research post at Queen's University, Kingston, Ontario.

A paper by Mr. L. E. S. Mathias, Mr. A. Crocker and Mr. M. S. Wills entitled "Sub-millimetre spectroscopic measurements on the laser emission from discharges in compounds of hydrogen, carbon and nitrogen" was read hy Mr. M. Wills at the Conference of Sub-millimetre wave Spectroscopy at N.P.L. on 22nd September.

Mr. R. Redstone and others attended a conferenee on Solid State Devices at Manchester College of Seienee and Technology at the beginning of September. A paper on gallium arsenide lasers was presented by Mr. C. H. Gooeh in eonjunetion with Mr. C. Dobson and Mr. F. Keeble of Standard Telephone Laboratories.

Messrs. K. G. Hambleton, R. J. Sherwell and C. S. Whitehead attended the C.V.D. Symposium on Mierowave Integrated Circuits at Nottingham University, September 12th-14th.

Books available for Review

Offers to review should be addressed to the Editor

Circuits for Digital Equipment.
C. J. Dakin and C. E. G. Cooke.
Iliffe Books Limited. 1967. 105s. (No. 1561).

Electronic Counting Circuits.
J. B. Dance.
Iliffe Books Limited. 1967. 85s. (No. 1562).

Theory of Automatic Control.
H. Takai.
Iliffe Books Limited. 1967. 75s. (No. 1563).

Hydraulic and Electrohydraulic Servo Systems.
R. Waters.
Iliffe Books Limited. 1967. 45s. (No. 1564).

Progress in Applied Materials Research. Volume 7.
Edited by E. G. Stanford, J. H. Fearon, and W. J. McGonnagle.
Haywood Books. 1967. 95s. (No. 1565).

Fundamentals of Ultrasonics. 2nd Edition.
J. Blitz.
Butterworth & Company (Publishers) Ltd. 1967. 38s. (No. 1566).

Project Planning and Control. Simplified Critical Path Analysis.
D. C. Robertson.
Heywood Books. 1967. 35s. (No. 1568).

Language, Logic and Mathematics.
C. W. Kilmister.
English Universities Press Ltd. 1967. 25s. (No. 1569).

Mosfet in Circuit Design.
R. H. Crawford.
McGraw Hill Publishing Co. Ltd. 1967. 81s. (No. 1570).

Modern Communication Principles with Application to Digital Signalling.
S. Stein.
McGraw Hill Publishing Co. Ltd. 1967. 120s. (No. 1571).

Book Reviews

Tensor Analysis of Networks. By G. Kron. Pp. xiii + 360. London. Macdonald & Co. (Publishers) Ltd. 1965. Price 70s.

One of the properties of a textbook required by the reader apart from factual accuracy, is a sense of confidence in the author. In this case the overlong introduction, consisting of an elaborate analysis of the contents combined with several passages of self praise, goes a long way to stifling any desire to read further.

How many students read introductions however? Oddly enough the text nearly redresses the balance. In a volume consisting of 620 pages, about one tenth is devoted to the last two chapters; one on analysis and the other on synthesis of networks. The preceding chapters deal mainly with two generalisation postulates, putting into tensor form complete networks and elements such as multielectrode tubes and interlinked electric and magnetic networks. However there are five chapters devoted to mathematical topics, for example the algebra of N way matrices, tensor analysis and geometrical interpretations of tensors and a section on theory of groups. This is all well done but in the reviewer's opinion, too much use is made of diagrams to give intuitive meanings to logical arguments.

This book is one for prolonged study, as an index of nine pages indicates. An extensive bibliography is also provided.

Worth the price, one feels, but only just.

D. P. Valler

Solutions to Problems in Engineering and Geometrical Drawing. By R. B. Matkin and S. A. Saunders. Pp. x + 133. London, Macdonald & Co. (Publishers) Ltd. 1967. Price 15s.

This is not a textbook of engineering drawing. It is a set of graded problems, with solutions, suitable for students. There are over 80 examples ranging from "O" level papers to degree papers from various universities. These are well selected and the solutions offered are, in most cases the best. The drawings are made to the British Standard for Engineering Drawing BS 308 and are well prepared and presented apart from such typographical errors as the mixing of captions on Page 12.

Students, preparing for examinations, will find these exercises very useful and would be well advised to read and follow the advice given on the page on Examination Procedure.

A. Maciver

Workshop Processes and Materials. By J. Schofield. Vol. 1. London and Glasgow. Blackie & Son Ltd. 1966. Price 17s. 6d.

The author endeavours to cover too much territory in a book of this nature. As this is Vol. 1, presumably to be followed by other volumes, more detailed information could have been presented on fewer subjects. Some specialised branches of engineering, such as Rolling, Casting, Extruding, Forging, Drawing, receive lengthy treatment of not too concise a character, whereas more general practices are touched lightly.

The approach to marking out, and measuring instruments is archaic, with too much attention to calipers and scribing blocks.

Chapter 2 on materials is well presented when one considers the complex nature of this subject, since it is one that is difficult to describe without being highly technical. All the simple characteristics of the materials are presented in a basic fashion that is interesting and informative. Put across in this way it should encourage the student to seek further knowledge on the subject. The mention of plastics helps to divert the attention of the student into a field of materials which already has a major place in engineering industry.

The most outstanding contribution is one that usually gets short shrift, *i.e.* safety and safe practices. The first chapter is devoted to this subject and then every opportunity is taken throughout the book of emphasizing safety considerations.

The book is disappointing in that it lags behind modern ideas of apprentice training. An apprentice even in his first year should be taught to become machine minded. When one considers the rapid advances in machining tools, and their uses, it raises a doubt whether the emphasis given in the book to the training in the use of cold chisels, scribing blocks, and pieces of chalk is altogether justified. One would hope that a successor to the present volume with a more modern approach will soon be available.

S. Field

Introduction to Atomic and Nuclear Physics. By R. D. Rusk. Pp. xiv + 470. London. Iliffe Books Ltd. 1965. Price 63s.

An "introduction to atomic and nuclear physics"; the use of the word introduction for the title of a book has different implications depending on the author and the subject but in this instance I think that it is justifiable. The undergraduate of today is confronted by many concepts and in order to interpret these he requires a well written introduction to his subject; this being as true for atomic and nuclear physics as any other topic. The subject of atomic and nuclear physics has expanded so rapidly that it is now probably impossible to prepare a text in which a detailed treatment of all aspects can be covered in a single volume. Therefore the author must select his topics and present them in a manner which satisfies the objective of his book.

This book is aimed at the student taking a general degree in physics, and covers most of the subject matter necessary for an understanding of modern physics. It is written from the modern viewpoint and considerable effort is devoted to emphasizing the successes of the application of relativistic and quantum concepts. The presentation is almost entirely descriptive, only a minimum of theory being included to provide a basis for the understanding of the fundamental principles. The narrative is well written and in general well illustrated with over 200 illustrations, the layout and type face also contributing to a well prepared book.

The first two chapters provide an introduction to the terminology, together with useful sections on the effect of magnetic and electric fields on a moving charge. The author then deals with mass spectroscopy; x-rays; the quantum properties of waves and particles; relativity; and the nuclear atom. The latter section includes a short historical introduction, an outline of Rutherford's alpha particle scattering theory, and a clear presentation of the Bohr theory of the hydrogen atom. The following chapter deals with wave mechanics, and its application to the

hydrogen atom, and a comparison is made between the methods of Bohr and Schrödinger. At this point the author includes a chapter on molecular spectra which, although useful is possibly out of context, as is the chapter on solid state physics. The chapter on radioactive decay and detectors is rather brief and further reading would be necessary to obtain a working knowledge of these topics.

The book has a strong bias to atomic physics, and only two chapters on nuclear physics are included, with an additional chapter on neutron physics. The last named provides only an outline introduction to the subject, and perhaps the space devoted to molecular spectra and solid state physics could have been more usefully employed to expand the part of the book devoted to nuclear physics. The last two chapters on particles and particle accelerators provides an introduction to the topic and for a general course this is probably reasonable.

The book is well laid out, and the examples together with the suggested further reading provide a general degree student with a worthwhile book for background reading. The examples at the end of each chapter are divided into two groups, the more difficult ones being denoted by an asterisk, and it might be noted that at least one of these has been provided with the wrong solution despite the author's helpful comments in the question. In conclusion, this book gives a descriptive introduction to the subject but has insufficient detail to be a useful reference volume.

A. V. Yorke

Introduction to Mathematics. By C. C. T. Baker. Pp. xi + 143. London. George Newnes Ltd. 1966. Price 10s. 6d. (paperback).

This book deals with some of the topics which have recently appeared in the curricula of schools and colleges. Numeration systems, the laws of algebra, Boolean algebra of both sets and propositions, groups, topology, circuit algebra, linear algebra, vectors, mapping, statistics and probability are the topics introduced.

This seems a reasonably comprehensive and careful choice and my only regret here is that the notion of propositional functions is not included in view of their simplicity and overwhelming importance in mathematics, logic, science and even philosophy (Russell's 'celebrated theory of descriptions' for example). Schoolchildren will soon be learning what propositional functions are anyway; after all they use them already. A book such as this would be better for making this simple obvious advance now.

However, this remark is a suggestion for the second edition rather than a criticism, and second edition there will have to be if the book is to be a good one, for it contains a number of quite incorrect statements which will surely mislead most of those readers for whom it is intended.

In the section on sets the author writes that 'a set is said to be countable if its members can be placed in some order one member being first one second and so on'. It would be much better to say 'sequence' rather than 'order' in this sentence in view of the technical meaning of these terms. But much worse is that the classical theory of transfinite numbers allows the members of uncountable sets (the set of real numbers for example) to be placed in an order one member being first, one second, and one n'th for every finite ordinal n, every member having a unique successor, though not necessarily a unique predecessor. Such an ordering seems to satisfy his definition though I don't know what 'and so on' means. If this is so his definition is incorrect. It would be correct to say that a set is countable if its members can be put in a one to one correspondence with some or all of the finite cardinal or ordinal numbers. The idea of finiteness must be used (at least implicitly) in defining a countable set (which is not, of course, to say that a countable set is finite). His definition of a finite set, given later, is one which has a definite number of members. But he does not define 'definite' which is not used by other mathematicians in this connexion.

In the chapter on topology he makes the untrue and confusing statement: 'The shapes of Fig. 40 are also topologically equivalent'. He forgets to remove the bottom from his Klein bottle and states that Moebius discovered his band in the eighteenth century. In fact it was about 1865.

There are some criticisms of his four line introduction of the inverse matrix. His definition only applies to square and nonsingular matrices but he does not mention either of these conditions. His proof that if AB is the unit matrix then AB is the same matrix as BA consists simply in connecting these propositions by the word 'therefore'. An A has been left out as a premultiplier in his last formula which in the context is serious.

His chapter on probability asserts: 'Mathematicians have decided upon the following scale for measuring probability: 1 means that the occurrence is bound to happen: 0 means that the occurrence cannot happen'. This is quite wrong though the converses are true.

Other criticisms of this kind could be made and a number of more controversial ones, for example his doctrine that 'probability has nothing to do with such uncertainties as predicting the weather, but deals with such problems as the chance of, say, picking an ace from a pack of cards' seems very dubious to me.

However, the book is well set out, teems with diagrams and examples and I have the impression that it reflects considerable practical teaching experience. But it cannot be recommended with its present mistakes. It should not be a great labour to eliminate them in the next edition.

G. P. M. Heselden

Fibre Reinforced Materials. By G. S. Holister and C. Thomas. Pp. xiv + 154. London. Elsevier Publishing Co. Ltd. Price 45s.

In preparing for a research programme into the stress distribution around discontinuous fibre embedded in elastic and plastic matrices, the authors made a survey of the available literature on the subject, and this book is essentially a compilation of the information they garnered.

They deal briefly with the varieties of fibre available for fibre composites, and with the techniques employed in the manufacture of the filaments and in the formation of the composite materials. In twelve pages, mention is made of a large variety of whiskers, filaments and matrices including, in a footnote, the carbon filaments developed by R.A.E. and Rolls Royce. Combined with the generous list of references to published information in the U.K. and the U.S.A., the chapter provides a useful starting point for further delving.

Following this introduction, the authors present the work of a number of scientists aimed at the development of theories capable of predicting the strength and physical properties of fibre composites. For example, dealing with the longitudinal stress distribution along the fibre-matrix interface, they present five theories. The first is that published by H. L. Cox in 1952, followed by a theory development by N. F. Dow in 1963 based on a similar model. Each assumes that a perfect bond exists between the fibre and the matrix and that the lateral con-

traction of the fibre and matrix are equal. The equations derived by both have a strong similarity. A contrary model developed by J. Ogden Outwater Jr. in 1956 is thought to be more appropriate for reinforced plastics. In this the assumptions are that the load is completely carried by the fibres and that the thickness of the matrix surrounding the fibre is negligible. Later work in 1964 by Walter Rosen on a modification of Dow's theory is also given, and the fifth theory is that developed by Kelly and Tyson where the assumption is that the matrix is wholly plastic.

The authors go on to review the developments of these theories to cover the cases of discontinuous fibres, and their modifications to align them with the results of experiments such as were conducted by Tyson and Davies where they explored the stress distribution in a two-dimensional model of aluminium alloy fibres in araldite resin. The more limited information on the transverse stress distribution is also discussed.

Consideration is next given to the ultimate strength of composites and factors affecting it. They present in some detail the experimental evaluations of ultimate strength by Kelly and Tyson of a tungsten-copper system using continuous fibres, and go on to discuss the significance of discontinuous fibres, ductile and brittle fibres, elastic and plastic matrices, and fibre volume fraction. A theory for compression strength suggested by Dow, based on the elastic buckling of fibres, is shown to be in reasonable agreement with experimental results.

The remaining chapters deal briefly with the rather scanty amount of work they found on fatigue stresses, the effect of fibre orientation and physical properties—modulus of elasticity, modulus of rigidity, bulk modulus and Poisson's ratio. Here again the experimental evidence is largely derived from the work of Kelly and Tyson on the tungsten-copper system.

In publishing this book, the authors have made available to other research workers in the field an excellent survey covering the theoretical treatment, and allied experimental work, of fibre-reinforced materials. The designer interested in applications of fibre reinforced materials is, however, unlikely to find the book of any direct assistance.

C. T. Wright

Digital Simulation in Operational Research. Ed. by S. H. Hollingdale. Pp. xv + 392. London. The English Universities Press Ltd. 1967. Price 75s.

This book is made up of the opening address, three survey papers and 37 short papers delivered in the 14 sessions of an open conference at Hamburg in September, 1965, sponsored by NATO. Some sessions are followed by discussions which, understandably, are brief. Readers are likely to find a number of unfamiliar projects with, perhaps, one or two old friends.

Simulations described in the civil, or near-civil, field include: helicopter, ship and barge scheduling; road traffic behaviour, air traffic control and ship lock operation; maintenance and stock control; coal mining and colliery transport. The last-named paper lists two techniques used for variance reduction, but so briefly that their import cannot be discerned. A paper from the BISRA discusses their overall experience in simulation and tabulates the effort involved in producing their 28 programs.

Two papers describe high level simulation languages, and numerous others are mentioned. A paper on ARL's experience and comments from Johns Hopkins University explain why these languages are not so universally beloved for military applications. However, several military groups seem to find Fortran satisfactory.

The military papers do not lose by being in unclassified form. A paper from Stamford Research Institute describes work on intervisibility, a difficult key problem in the simulation of tactical ground battles.

An outline of the DOAE war game shows the complexity of army problems and explains why as yet such games are purely manual. The single paper on strictly naval problems describes French work on torpedo avoidance and AS barrier patrols. On the air side, a paper describes two USAF studies, each carried out by a manual method and a different computer method; results showed partial agreement. One paper outlines the structure of the STC Como II air battle model, but the ease of inserting arbitrary weapon systems into this framework may be over-stated. Another paper applies Como II to a low level defence problem involving terrain masks.

The above, by no means exhaustive, list will show the breadth of the papers. Correspondingly, some suffer from the lack of space to develop in depth. This is a paperback to dip into. The print is very clear, the glue is inadequate.

R. Hall

Principles of Ideal-Fluid Aerodynamics. By Krishnamurty Karamcheti. Pp. xvii + 636. New York/London/Sydney. John Wiley & Sons Ltd. 1967. Price 160s.

The only reader likely to be disappointed with this volume is the one who has been attracted by the word 'aerodynamics' in the title, nevertheless, if he thinks again, ideal fluid theory is a suitable introduction to the principles and methods underlying the study of more complex phenomena. Even so, he must wonder if the wings and bodies of revolution of aerodynamics are ever going to appear, although development of the theory begins immediately after an introductory survey.

The development, in fact, begins in Chapter 2, which is the longest in the book and is concerned with the elements of vector algebra and calculus. Then follow chapters on stress in a fluid, fluid motion, Eulerian and alternate equations of fluid motion, equations of discontinuous motion, the integration of Euler's equations in special cases and irrotational motion. These topics are, of course, the classical theories usually associated with hydrodynamics. The aerodynamicist who has stayed the course this far may begin to see daylight in Chapter 10, which studies the acyclic motion resulting from a rigid solid body translating through an infinitely extending ideal fluid. Two further chapters on steady acyclic motion exhaust this topic which includes, of course, the paradoxical result that the force on an arbitrary body is zero (d'Alembert's paradox). The connection between lift and circulation has been mentioned in previous chapters but it is finally examined in detail in Chapter 13 and the aerodynamicist must begin to feel at home as the names of Lanchester, Kutta, Joukowski and Prandtl are introduced. However, there is yet more ground work to be covered. Chapter 14 deals with the elements of the theory of functions of a complex variable and Chapter 15 with the representation of the two-dimensional potential motion of an ideal fluid in terms of the functions of a complex variable. At last, Chapter 16 introduces the problem of the airfoil and deals with the transformation of a circle into an airfoil-like profile, thus determining its properties; the alternative, more useful approach, provided by thin airfoil theory, is given in the following chapter. Having thus analysed the infinite wing, vorticity and the elements of finite wing theory are introduced in the next two chapters, with finally a chapter dealing briefly with the flow past a slender body of revolution. There are in addition a number of selected problems for solution and five short appendices.

Clearly, this is a very comprehensive book. Of course the subject matter is not new and can be found in many other books, however, this particular combination in such detail could probably not be found elsewhere in one volume. Furthermore, the production and printing of the book are of the highest standard, although the drawings of closed bodies are so beautifully shaded that they resemble prizewinning potatoes or exotic sausages. My only criticism of an otherwise very fine book, is of the literary style of the author—his meaning is quite clear but the continual use of the first person plural begins to cloy. I found myself wondering if this were some form of royal prerogative and even occasionally counting the number of times 'we' appeared per page—the maximum noted was eleven.

J. B. Spencer

Organic Chemistry (Teach Yourself Books). By K. Rockett. Pp. viii + 264. London. English Universities Press Ltd. 1967. Price 10s. 6d.

Organic Chemistry is a very broad subject and there are many ways of introducing it to readers with elementary chemistry to "O" level only. The author approaches the subject from the structural point of view and the structure of organic molecules is the main thread running through the book. The material is presented in a condensed form but is clearly and sensibly pursued. The reader with only an elementary knowledge will probably find that every page will require close study in order not to lose the thread but this study will be repaid.

The early part of the book deals in a conventional manner with chemical structure and the reactions of common organic compounds. There is a long chapter on isomerism, perhaps too long compared with the remainder of the book. The last chapters cover polymers and industrial organic chemistry. These sections are very welcome and the book would benefit by their being expanded since they bring realism into a subject which is too often taught as wholly academic.

There is an unfortunate chapter on organic analysis. The author is clearly on shaky ground here and does not seem to understand the principles he attempts to describe. Without this chapter the book presents a narrative beginning with the simplest compounds of carbon and concluding with complex polymers, their structures, manufacture and uses. The chapter on analysis is an unwelcome intrusion.

The book abounds in printing errors, some of them quite amazing, suggesting that proof reading has been careless. The adoption of very small print for some of the reaction sequences is trying.

M. H. Holness

Low Noise Electronics. By W. P. Jolly. Pp. ix + 139. English Universities Press Ltd. 1967. Price 25s.

The title of this book is misleading since it is really an introduction to electronics devices used in the communications field with very little reference to their noise properties. Indeed the treatment of any noise properties of the devices is one of the weakest points of the book. However, apart from the small matter of title, the author has achieved his aims expressed in his preface, namely to write an introductory book on masers, lasers, electron beam tubes, parametric amplifiers and associated topics (even Gunn effect is mentioned). The author hoped that his book would be like a toy cricket bat: light enough for the novice to get a feel for the game. It is certainly light reading but none-the-less gives a useful review of many recent developments in electron devices.

In its details one or two points suffer because of the lightness of the treatment. Four examples given below will suffice.

The definition of noise figure of an amplifier does not emphasise the difference between the available signal (or noise) power and the signal (or noise) power that actually enters the amplifier.

The classic explanations of parametric power gain (by reference to condenser plates being pulled apart and pushed together at critical times and examining the energy flow) are omitted presumably on the grounds of brevity. In any introduction to parametric effects the lack of any simple physical explanation of parametric energy gain is to be regretted.

The emphasis given to the Adler tube (a whole chapter) is misplaced. In retrospect one can see that the Adler tube was a brilliant idea that was invented too late. Its advantages, in terms of present day competing devices, are insufficient to outweigh its disadvantages. The author also has failed to follow the long-established reasons for the failure in noise performance of the d.c. pumped Adler tube.

The section on crossed field devices (Appendix III) is too light to be of use. There is no diagram and someone who had not met a magnetron or stabilotron would be none the wiser.

Points like these are relatively minor when one remembers the author's intention—a light introductory text to introduce the novice to the jargon and major ideas of a very broad field. In this respect the book can be said to be successful and worthwhile.

J. E. Carroll

Concise Intermediate Physics. By H. V. Pilling. Pp. xiii + 270 + 123. London. The English Universities Press. 1967. Price 25s.

In the author's preface he writes 'This work is an anthology of physics intended as a textbook for students of engineering and the physical and biological sciences . . .' It is in fact not a conventional textbook, to which a student should go for enlightment, but a book written to assist the student to pass his examinations. It is in two parts; the first is the text, the second a collection of worked examples in physics and examination questions for the student to practise on.

The text is a summary of the main branches of physics at about GCE Advanced level. There are 16 chapters in its 270 pages, each reading rather like the perfect lecture notes. The book is most aptly titled; alternating currents are dealt with in nine-and-a-half pages, magnetism in eight-and-a-half. The text, though brief, is quite good. The transformer is described thus:

> 'The name derives from the idea of transforming voltages from lower to higher values, or *vice versa*, using the properties of mutual inductance between closely coupled windings.'

The tangent galvanometer:

> 'This instrument measures current strength in terms of the magnetic field it produces at the centre of a circular coil.'

The student producing this type of answer in his examinations could hardly fail to get good marks.

In Part 2 there are over 100 worked examples and nearly 300 questions and exercises, together with the answers. Finally there is a ten page glossary defining terms used in the text. The book is available in two versions, identical except that one is written in MKS units, the other in CGS units. This is not a book for the technical library, but one the student should consider buying for himself, providing of course that he doesn't show it to his teacher.

J. E. Wood

Magnetic Domains and Techniques for their observation. By R. Carey and E. D. Isaac. Pp. viii + 167. London. The English Universities Press Ltd. 1966. Price 50s.

In recent years a great deal of information has been learned about the properties of ferromagnetic materials through the study of magnetic domains. However, it is difficult to find a recent comprehensive account of even the most common technique employed for domain observation. In fact there is a considerable amount of knowledge concerning many recently developed techniques and modifications to existing methods which is available only in scientific papers. This book has been written to try to fill the gap in available textbook literature and to give an up-to-date review of the various techniques.

It begins with a general account of the conditions which are responsible for ferromagnetism and the processes which occur within various types of ferromagnetic material. Sections are included which deal with magnetic anisotropy, magnetostriction, coercivity and irreversible processes. It is shown that the subdivision of a ferromagnetic crystal into domains occurs naturally as a result of minimising the free energy of the magnetic system. There is also a discussion of the effects of mechanical stress on domain shapes and domain walls.

The next part of the book covers in considerable detail, techniques employed for domain observation. One chapter is devoted to each of the principal techniques and these include the Colloid, Magneto-Optical, Electron beam and Probe methods. In each case the historical origin of the method is stated and an outline given of the fundamental principle on which it is based. A full description of the technique then follows with all modifications mentioned in chronological order. Finally an indication is given of the limitations of the various techniques.

The book is very well illustrated. There are some excellent pictures of domain patterns and many photographs and drawings of the experimental equipment discussed in the text. These photographs are extremely useful in enabling the reader to appreciate the problems involved in domain observation. The book is well planned with the chapters following in a logical sequence. The mathematics has been kept to a minimum, but when used, the treatment is clear and concise.

Thus it can quite definitely be stated that the book fulfills its aim as mentioned above. However, it is difficult to see just for whom it is intended. The scope is rather larger than that required for a typical first degree course although some sections will undoubtedly be useful to students on such a course. It will also provide a good introduction to the subject for a new research worker about to embark on some studies in the field. However, one is left with the impression that although the book fills a gap in readily available literature it will not have a wide appeal. It is too expensive for students to purchase as a general reading book and would quickly be outgrown by the research worker. The standard is really that required for part of a one year post-graduate course. Thus it seems likely that the book will be found only in the libraries of educational and similar establishments. It cannot really be recommended for student purchase as there are many other books which fulfill their requirements better than this one.

R. G. F. Taylor

General Chemistry. By N. Glinka, translated by D. Sobolev. Pp. 694. Price $17.50.

Organic Chemistry. By B. Pavlov and A. Terentyev, translated by B. Belitzky. Pp. 568. Price $16.00.

Engineering Physical Metallurgy. By Y. Lakhtin, translated by N. Weinstein. Pp. 471. Price $14.50.
New York; Gordon & Breach, Science Publishers.

For many years now, the accelerating advancement of Russia in the fields of science, engineering and technology has been evident. In relatively recent years this has been demonstrated by the appearance in the West of a considerable number of learned papers of Russian origin. Indeed, there are journals published in the U.K. which are devoted to Russian material. Whilst many important developments are shown in these papers, it is inevitable that duplication of the efforts of other countries must occur and this applies, of course, to text books as well.

A series of Russian monographs and texts is being produced by the publishers of the above three volumes, which are of this series, covering many aspects of pure and applied sciences. Whatever the range of topics, a uniformly published series of works often has more value and is generally more acceptable than works of diverse origin. There are several points which contribute to the success of such a series but it is not yet known whether the following points, derived from the three volumes above, apply to the whole series.

Generally, the volumes offer comprehensive treatments of their respective subjects, starting with the elementary and the fundamental and logically developing the subject matter. The texts are liberally illustrated and contain examples where appropriate based on the laws or phenomena covered. Considerable reference is made, naturally, to the work and literature of Russian scientists but not to the exclusion of non-Russian material. Each text has been translated from the original Russian and the quality of translation varies from book to book and even within one book, making the text somewhat unreadable in part. At such times the translation could use, for want of a better expression, an "external examiner" to put the translated material into more conventional English. This is of course an aspect of language development to suit the needs of ever-specialising technologies and branches of science and, as such, the criticism can be applied to a far wider field than inter-language translations. Occasionally, American-style English reminds one of the comment about two nations divided by a common language.

A specific criticism, in view of the fact that these volumes are three of a uniform series, is that the typeface is not consistent from volume to volume.

The above notes are generally applicable, but a few individual comments on each volume are worthwhile.

General Chemistry

The opening list of 26 errata, evidence of poor proof reading, is not a good introduction. It is unfortunate that this should be the case with such a comprehensive text. There is evidence that when the author deviates from his strictly chemical field into allied topics, his information is out of date. Whilst no book of this nature can be fully up-to-date, some allowance or explanation ought to be included.

Organic Chemistry

The translation is into more conventional English, but the poor choice of typeface and uneven printing is not conducive to easy reading. Some of the text applies,

not unnaturally, to Russian industry but even so the usual spellings, of kerosine and gasoline for example, ought to be adopted.

Engineering Physical Metallurgy

This volume, again with Russian industrial emphasis, is aimed particularly at students and recent graduates. The printing quality deteriorates badly in places and the graphs and photographs are of variable quality.

Summarising, therefore, it can be said that these three books are comprehensive works of their kind with an elementary and fundamental approach but suffer from translation, typeface and printing troubles. If the points mentioned were to receive attention, then the books would be most acceptable to any library but at present, particularly in view of the price, it is felt that their competitors will prove far more attractive.

M. E. Horsley

Mathematical and Geometrical Techniques for Symmetrical Component Fault Studies. By S. Austen Stigant. Pp. ix + 110. London; Macdonald & Co. (Publishers) Ltd. 1965. Price 25s.

Accurate predication of the maximum possible fault currents in an electric power system forms the basis for both the choice of circuit-breakers and protective gear, and the estimation of the most severe physical stresses likely to be suffered by the system. With unbalanced faults in a three-phase system, such calculations can become laborious affairs when based upon straightforward application of the Kirchhoff laws. The advent of computers, both digital and analogue, obviates much of this drudgery but the well-established method of symmetrical components is still the basis of many fault studies, and likely to remain so.

Mr. Austen Stigant is a well-known authority on power system analysis and his book deals systematically with the calculation of faults by the use of symmetrical components. The method depends upon the fact that the actual currents arising from any unbalanced fault condition in a three-phase system can be represented by three sets of balanced, or symmetrical, 'sequence' components. Each set comprises three equal current components and the distribution of the nine components between the three phases is determined by the conditions of the problem and by certain other simple restrictions inherent in the method. A problem in unsymmetrical conditions thus becomes a problem in symmetrical conditions, with much saving of time and effort.

The basic equations connecting the phase value and their sequence components are few and simple, but the variety of conditions involved in their application is wide enough to create the need for a systematic presentation of the permutations. This is well accomplished in a book which, although intended primarily for reference purposes, nevertheless expounds the theory adequately. Rapid analysis of many practical unbalanced conditions is eased by the tabulated presentation of appropriate equations, together with matrix forms and an abundance of helpful diagrams.

A suggestion of repetitiveness is inevitable in a scheme of this kind, but the more lasting impression is of a substantial body of very useful information contained within a surprisingly small volume. It is a work aimed much more at the systems engineer than at the student.

P. H. G. Crane

Power Travelling-Wave Tubes. By J. F. Gittins. Pp. xii + 276. London; The English Universities Press Ltd., 1965. Price 50s.

The principles of travelling-wave amplification were first demonstrated in 1943 and the first commercial travelling-wave tube appeared in 1952. Built by Standard Telephones and Cables this tube was used by the G.P.O. in a television transmission link between Manchester and Edinburgh. The tube was capable of outputs of two watts over a 20 per cent frequency band at four GHz. Since that time the travelling-wave tube has been extensively developed until today tubes are manufactured for operation in all the microwave bands with power outputs up to kilowatts, continuous output and megawatts pulsed. Mr. Gittins, the author of this book on high power travelling-wave tubes, has been involved in their development and construction at the Services Electronics Research Laboratories for the past 10 years. During this time he has accumulated a vast fund of experience, probably unique in this country. Much of this experience is incorporated in this book which, while being primarily aimed at the engineer who designs and constructs travelling-wave tubes, should also be of considerable interest to anybody concerned with high power microwave work. While being essentially a book concerned with the practicabilities of the device, it does contain a considerable amount of basic theory, essential to a proper understanding of the subject.

Perhaps one of the most difficult parts of this theory is the description of the amplification mechanism. Most books on the subject either give only a qualitative account or an involved mathematical treatment, neither of which is very satisfactory. There is an unfortunate modern tendency for mathematics to be very abstruse and often detached from physical reality. This criticism cannot be levelled at Mr. Gittins, who, by using a simplified model and a vector approach formulates a very lucid explanation which links the mathematics closely with the physical aspects of the device. Throughout the book a good balance has been achieved between the mathematical and engineering aspects of travelling-wave tubes.

The intention of this book is not to give a detailed design procedure but rather it presents a logical approach to the various problems encountered in the construction of travelling-wave tubes. Several chapters are devoted to the historical background and basic theory of the device while later chapters deal with the various component parts such as guns, slow-wave structures, focusing systems and vacuum windows. Each chapter is well illustrated with clear line drawings and graphs.

One of the most interesting chapters is that devoted to the various manufacturing techniques employed. Mr. Gittins gives a comprehensive description of the different methods of brazing and welding used and enumerates the advantages and application of each. The actual pumping and baking processes which each tube undergoes are described in detail. These are long, complicated processes and for a large tube, they may take over a week to complete and must be carried out under very exacting conditions of temperature and pressure. It would seem that the construction of travelling-wave tubes is still very much an art and the experience of the manufacturer is of great importance.

This book fills a long awaited need for a book on the practical design aspects of travelling-wave tube construction and can be strongly recommended to anybody concerned with high power microwave tubes.

T. P. Crowfoot

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Printed in England by Lightbowns Ltd., 72 Union Street, Ryde, Isle of Wight.

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AD#:
Date of Search: 15 February 2007

Record Summary:

Title: Journal of the Royal Naval Scientific Service
Covering dates 1967 Nov
Availability Open Document, Open Description, Normal Closure before FOI Act: 30 years
Note Vol 22 No 6 Index to Vol 22
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